LA-UR-19-20124
Approved for public release; distribution is unlimited.

Title: LA-43-S-CT Post Shot

Author(s): Goforth, James H.; Armstrong, Christopher Lee; Baca, Eva V.; Dickson, Peter; Foley, Timothy J.; Gunderson, Jake Alfred; Herrera, Dennis H.; Rae, Philip John; Rousculp, Christopher L.; Watt, Robert Gregory; Haroz, Erik H.

Intended for: Report

Issued: 2019-01-10

LA-43-S-CT Post Shot

Jim Goforth, Chris Armstrong, Eva Baca, Peter Dickson, Tim Foley, Jake Gunderson, Dennis Herrera, Philip Rae, Chris Rousculp, Robert Watt

Los Alamos National Laboratory

Erik Haroz

Mission Support & Test Services- Los Alamos Operations

Abstract

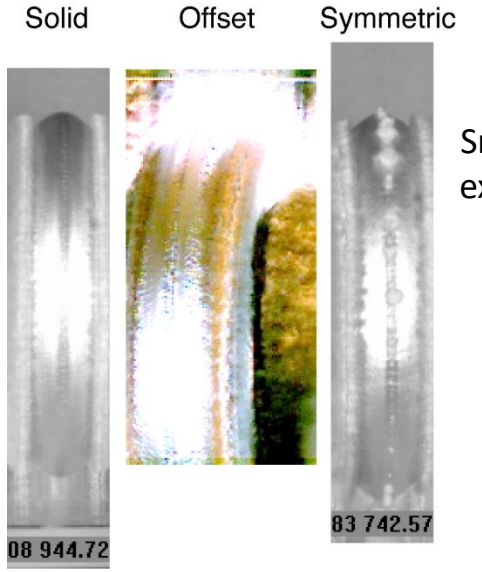
LA-43-S-CT was conducted on 12/14/15to verify the performance of the HE/Armature system intended for use in a new configuration of Ranchero Flux Compression Generators (FCGs). Subsystem tests preceded this experiment, and a synopsis of the issues explored in these is presented. The system was viewed by two fast framing cameras, an array of PDV probes, and an electronic streak camera that provide very good time and space resolution for motion of the armature during expansion. The test is described in very good detail, and the result is that the armature system is adequate for use in the Ranchero 43-S system for future physics tests.

Introduction

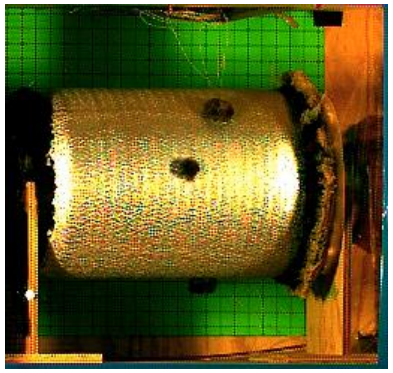
- LA-43-S-CT was conducted on 12/14/15 to demonstrate that a PBX 9501 high explosive (HE) charge could be assembled from machined pieces and drive the armature intended for the new LANL “swooped” generator.
  - LA-19.4-CT-2 had demonstrated that PBX 9501 directly coupled to a 6 mm thick 6061 fully annealed aluminum armature would not destroy the armature with its fast high pressure shock front (as opposed to the PBXN-110 castable explosive with which all previous Ranchero FCGs had been driven).
  - Small scale tests had shown that glue joints which were adequately thin would not cause the armature to rupture
  - LA-43-S-CT was to show that the complete system could be made with adequate precision for a full scale FCG.
  - LA-43-S-CT was to also show that the armature in the “swoop” region would behave as in calculations
  - Two ER-515 slapper line initiators were used back to back
  - 6 mm diameter, 3 mm thick standard grade PETN pellets at 1.65 g/cc were used for each slapper point
- The armature was sized to use “as pressed” 6” diameter cylinders to avoid the machining step of finish machining the OD of the cylindrical charges.
- Camera and PDV diagnostics were used
- 2X expansion without rupturing was the experimental goal

Ranchero camera tests since 2010 have advanced our knowledge of how to drive Ranchero armatures

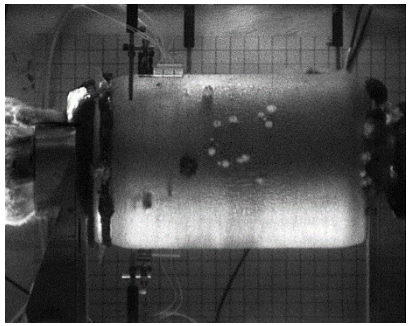
- LA-43-CT-1; 1/11
- LA-43-CT-2; 6/13
- LA-19.4-CT-2; 9/13
- Several “glue joint” tests were also performed



Small scale tests were conducted to explore possible bad effects of glue joints in PBX 9501 assemblies. Explanation below



Ranchero Armature using PBXN-110 and with smoother; 2X expansion. LA-43-CT-1; 1/11. Blowouts were in pre-shot identified bubble locations and were predicted.

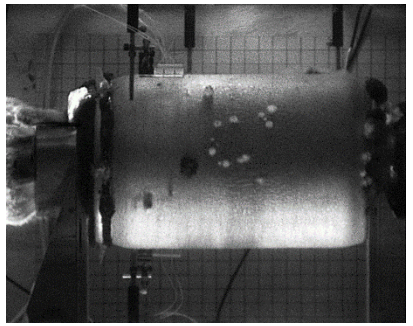


Ranchero Armature using PBXN-110 HE and without smoother; 2X expansion. LA-43-CT-2; 6/13. “Black” blowouts were due to identified bubbles. “White” blowouts were not predicted.

Ranchero Armature with PBX-9501, without smoother; 2X expansion. LA-19.4-CT-2; 9/13. Armature good condition; surface better where buffed to make PDV signals better.

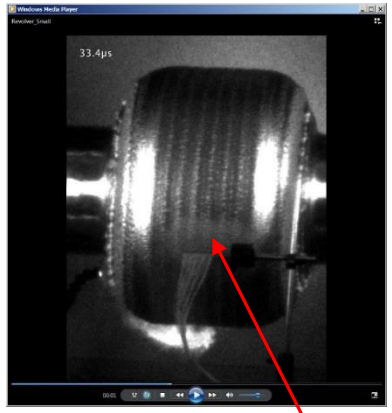
LA-43-CT-2 Showed that the “smoother layer” wasn’t necessary (LA-UR-14-21983)

- Armature is smooth enough w/o smoother
- Bubbles cause armature to rupture in locations where they were observed.
- A set of ruptures occurred that were not predicted from pre shot inspection.
- A further understanding of the currently un-predicted ruptures is required to use the remaining two armatures in FCG tests.
- There are 23 bright ridges on the armature, indicating that they are over the shock wave interaction region rather than over the pellets.

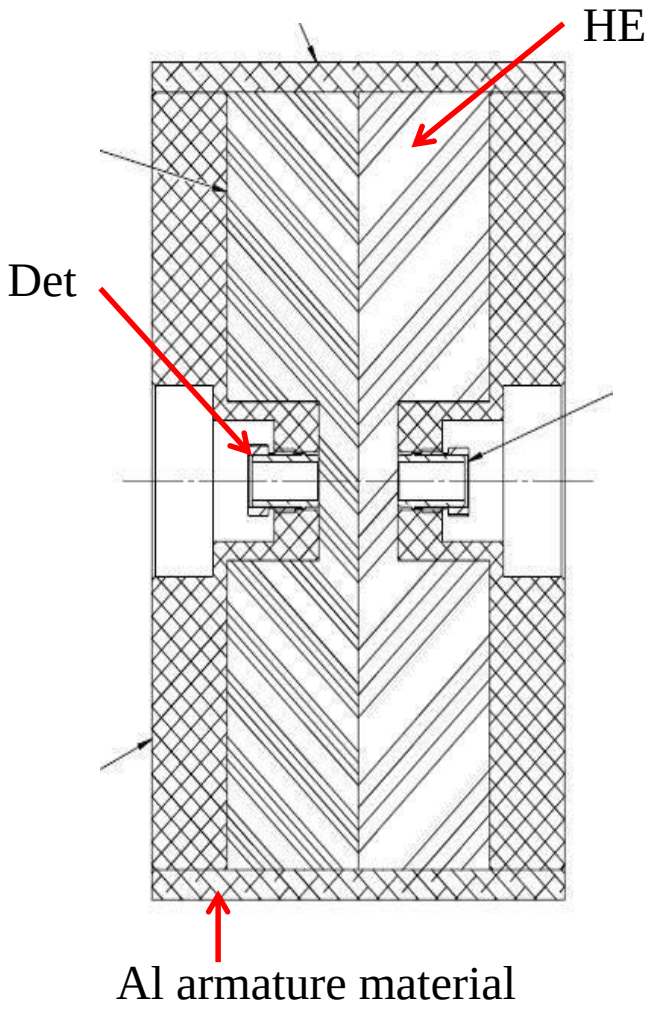


LA-19.5 CT-3 Showed that 9501 would not destroy armature (LA-UR-14-28810)

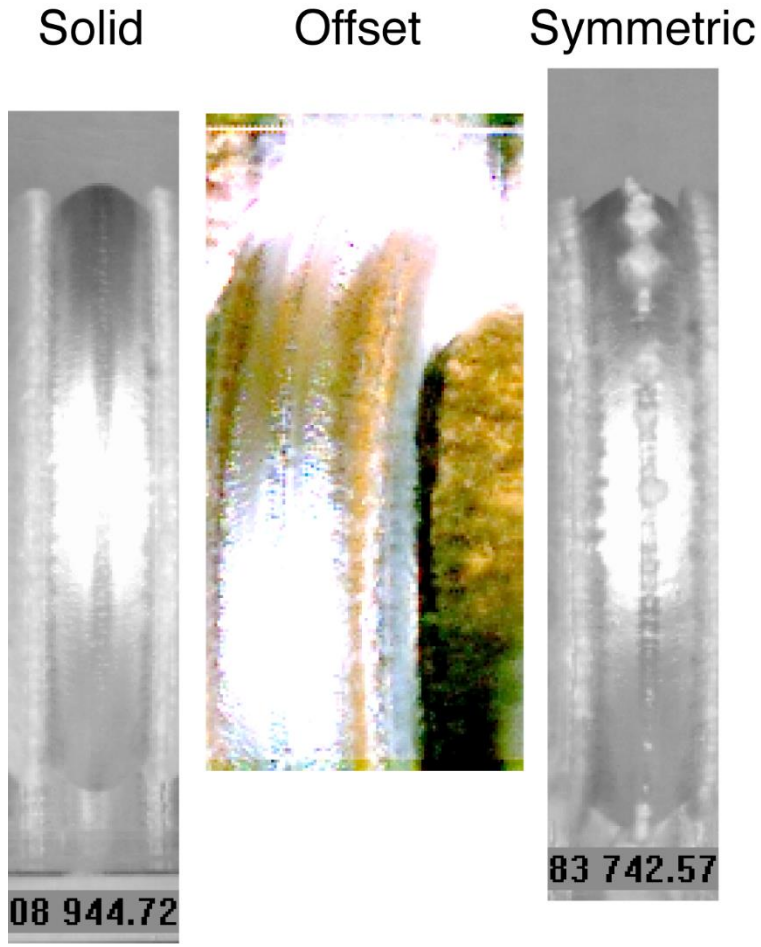
- PBX-9501 does not break up the 6 mm thick annealed 6061 Al armature
- Gaps as big as .005” and the seam caused by the edge of a .005” Mylar shim do not show up (don’t cause a problem). We will still strive for the best possible fit.
- Armature velocity is 3.8 mm/µs, as compared to 3.3 mm/µs for PBXN-110 without smoother and 3.1 mm/µs for PBXN-110 with a smoother. The time to travel 76.2 mm from first motion is less than ~22 µs for this test, as compared to ~25 µs for LA-43-CT-2. This time difference was not carefully measured on LA-43-CT-1, but it will be even larger on that test.
- Breakout patterns measured with PDV probes show that ripple due to detonator spacing is small compared to detonator jitter.
- PDV probes show that the armature spalls, then recollects.
- Recollection times do correlate to detonator position, the recollection being earlier above dets, and later in between them.
- The “buffing” performed to facilitate good PDV signals is likely a good practice for FCG armatures, as the camera results seem to show less “fluff” leading the armature in the buffed area.



To build a Ranchero Armature with PBX 9501, machined pieces have to be glued together. Small scale tests reported in LA-UR-15-23837 were conducted to determine if acceptable glue joints could be made. The tests shown here demonstrated that the shock wave interaction between two initiation pellets must not be allowed to run down a glue joint



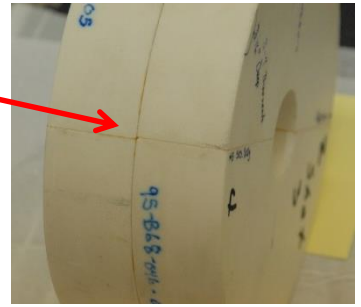
- The baseline HE design for Ranchero assemblies had a glue joint exactly half way between two slapper detonator points, and some calculations showed the armature rupturing adjacent to the joint (some did not).
- All calculations with the glue joint offset by 3 mm from the center showed that the gap would not rupture
- 30 mm thick, 155 mm diameter PBX 9501 charges were detonated in counterbores which spaced the detonators 18 mm apart.
- One control test was fired with no seam in the explosive ("Solid" in the figure to the right)
- One test was conducted with the glue joint halfway between the detonators ("symmetric") in the figure to the right.
- One test was conducted with the glue joint offset 3 mm from the symmetric point.
- The "solid" test shows the shockwave interaction, but does not rupture
- The "Symmetric" test shows significant rupturing
- The Offset shot shows the shock wave interaction, but no rupture along the glue joint.

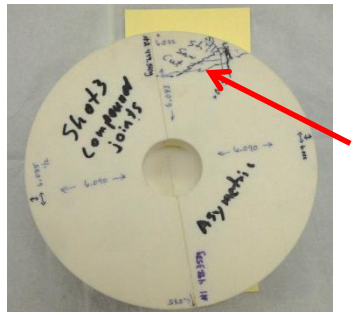


Another test, reported in LA-UR-15-23837, showed that a compound joint with a 0.005” flaw would rupture

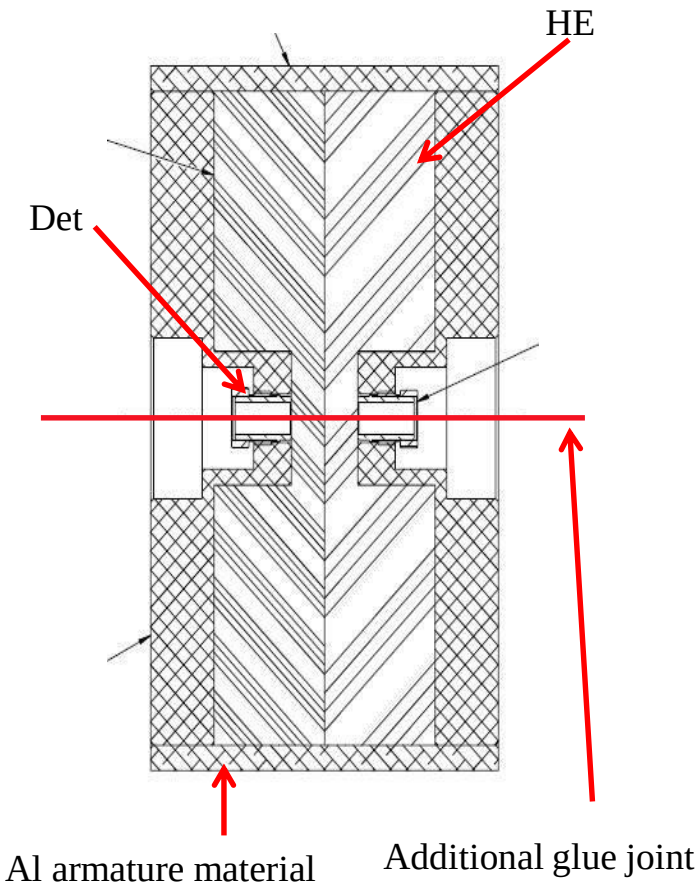
- On this test, another glue joint was imposed by cutting the PBX 9501 charges into half cylinders along the red line shown to the right
- The decision was made to continue with the manufacture of the 43-S HE
  - Be as careful as possible in assembly
  - The rupture observed may not hurt generator performance
  - Challenge codes to predict performance with rupture
  - Conduct a full scale armature test for 43-S

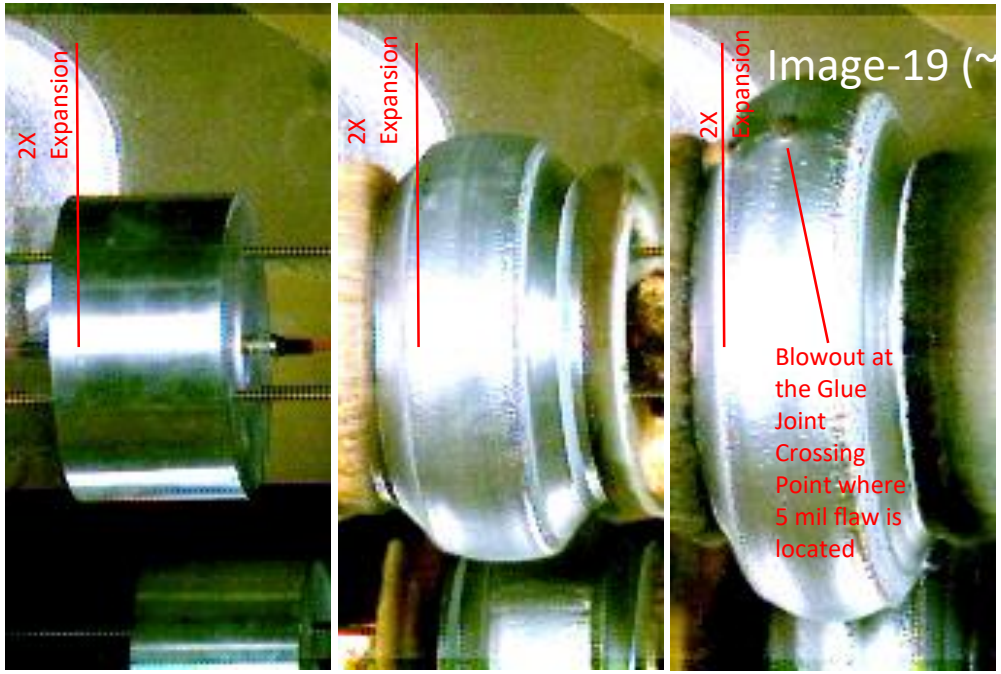
Additional glue joint leads to compound joint where the four pieces come together





One of the half cylinders shown here was not machined to flat on the corner indicated, leaving a 0.005” gap at the edge of that compound joint

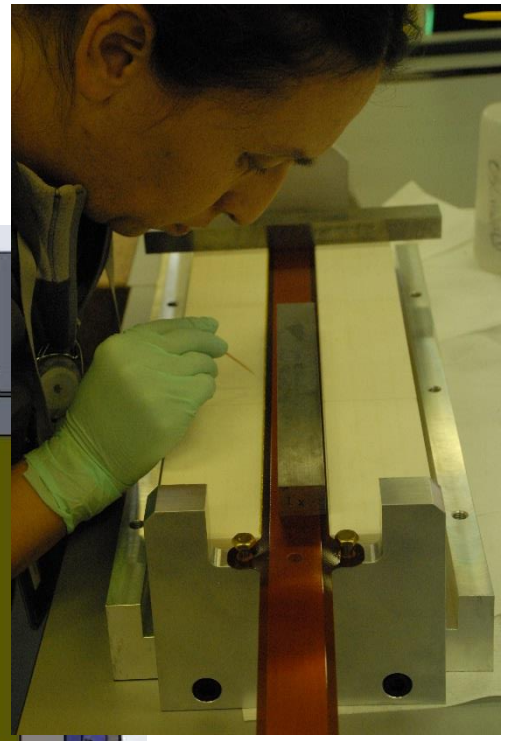


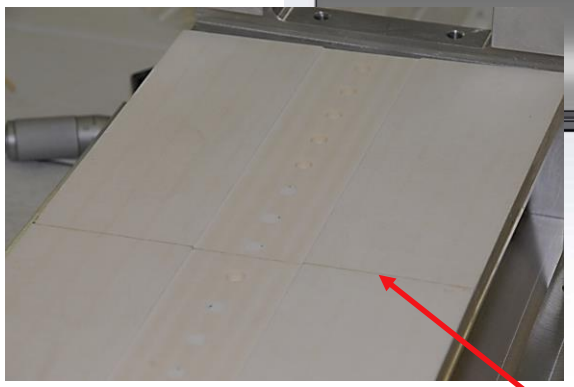


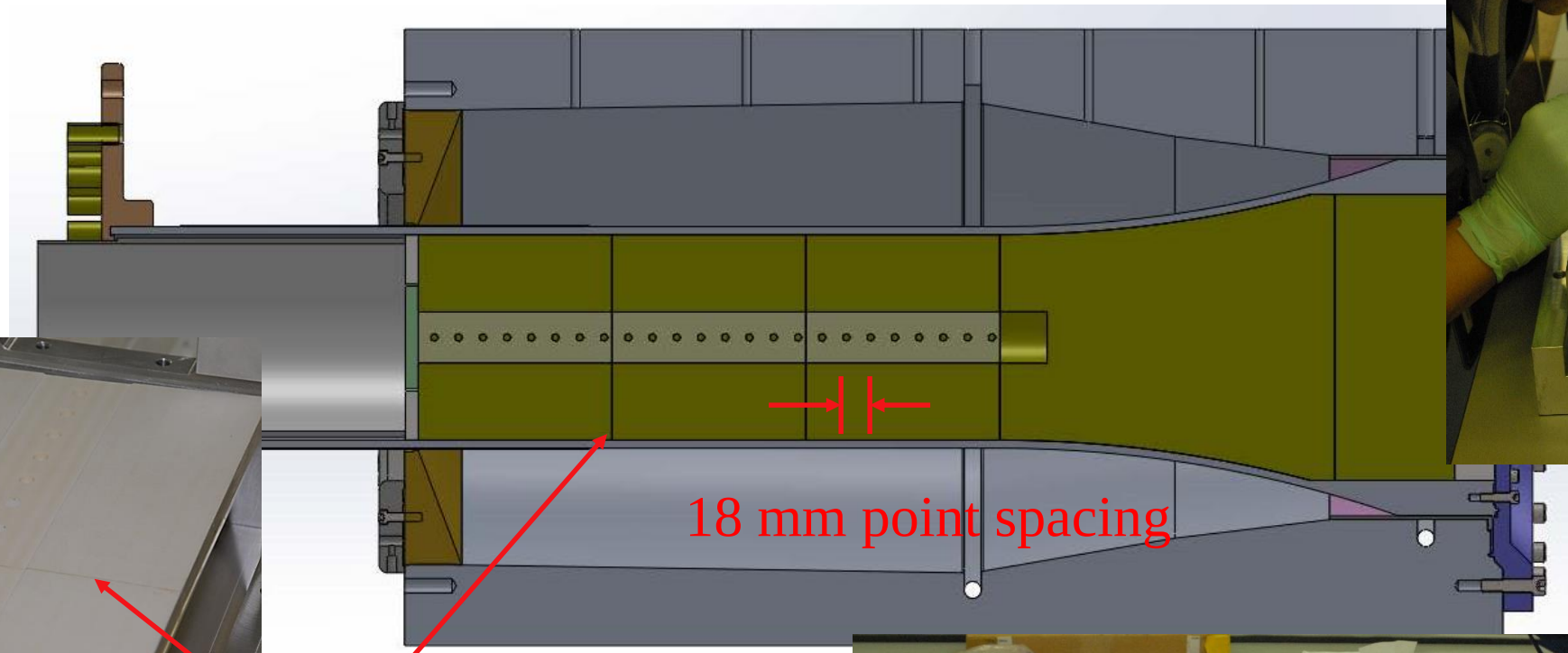
Compound joint without the machining flaw is good in the middle frame, but is occluded by the time the flawed joint has ruptured, so no data on a good compound joint was obtained on this test. The compound joint with the 0.00t” flaw ruptured as shown, before 2X expansion.

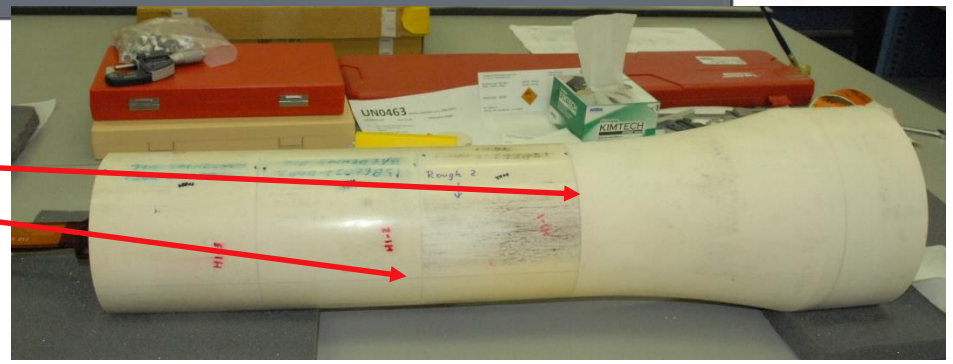
After the preliminary tests discussed above, LA-43-S-CT was conducted to test the Armature, HE configuration, and glue joints in a full up 43-S configuration

Ranchero 43-S



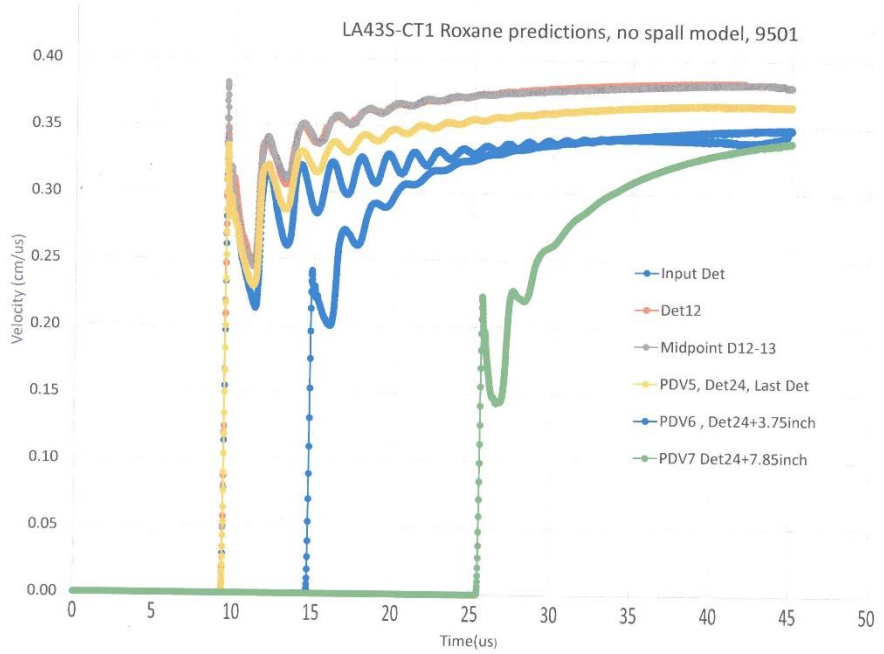


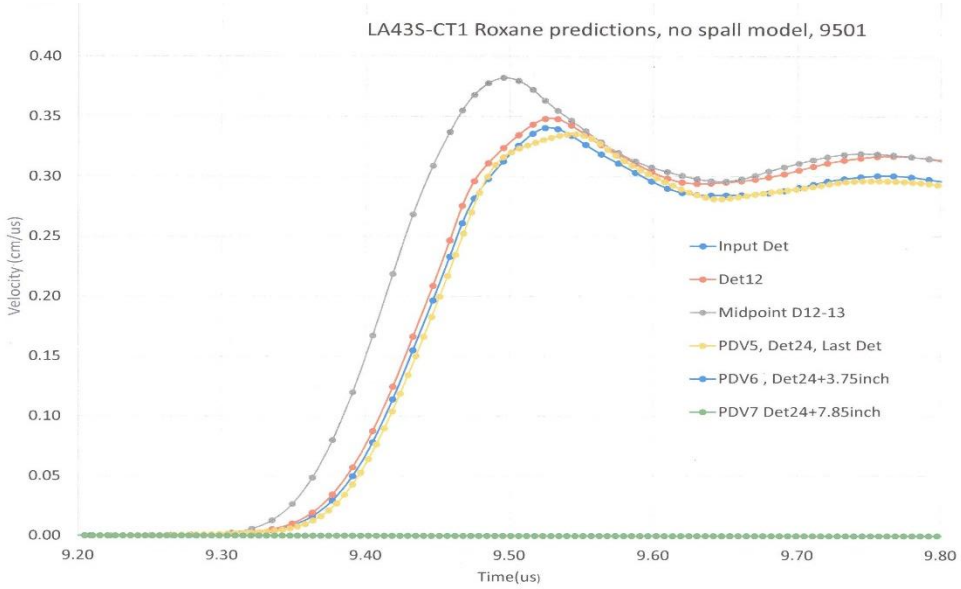


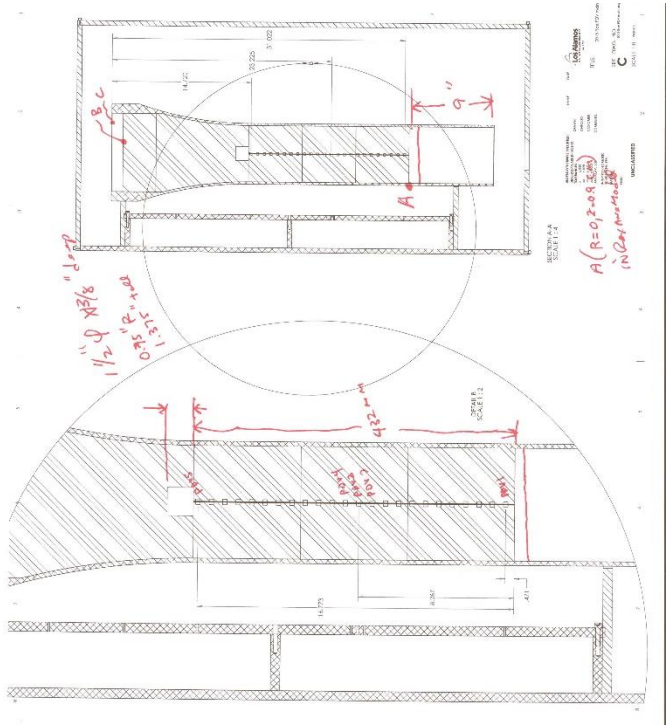


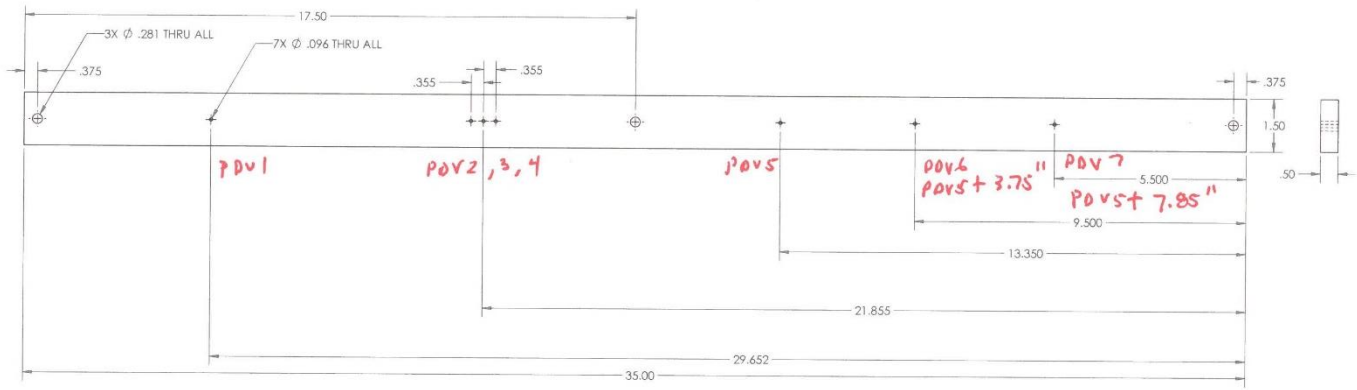
Significant development step is proving glue joints can be made with adequate quality on a full scale assembly

Roxane calculations made pre-shot predictions









A new lot of ER-515 slapper systems were made and QC tested for the 43S series

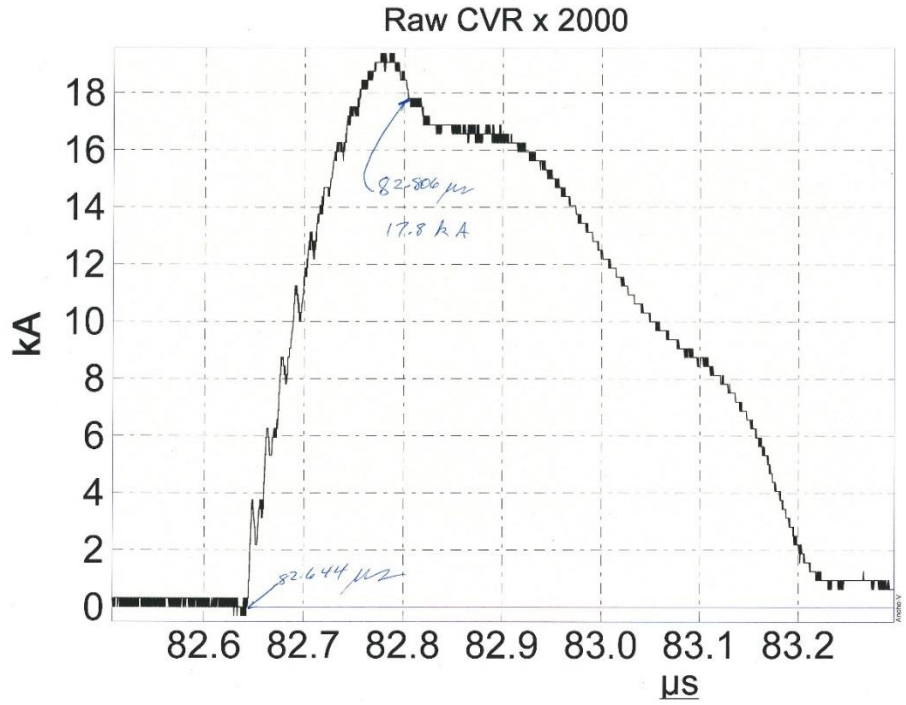
- Three pairs of 24 point cables with microclad shock switches were tested
- These slappers were the continuous microclad variety (as opposed to “bowties”)
  - Matched low Resistance cables were 142 mΩ
  - Matched middle Resistance cables were 169 mΩ & 175 mΩ
  - Matched higher than ever seen Resistance cables were 279 mΩ
- All fired with a 1 µF X-Unit at 8.5 kV
- Microclad shock switches were consistently timed

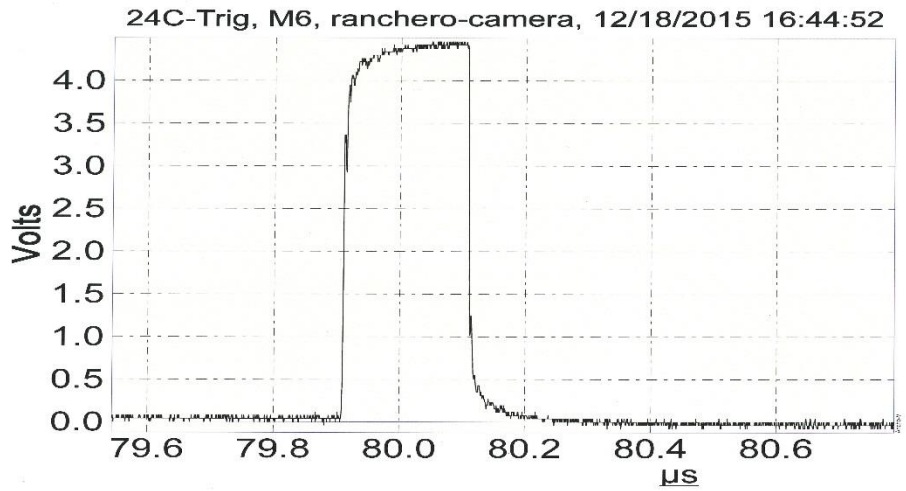
Shot timing

- ~100 µs was required for the flash for the streak camera to achieve adequate brightness for the back lighting
  - Flash triggered at “0”
  - Scopes triggered at “0”
  - The Phantom camera was set for hundreds of microsec of pre-trigger
- From scope records:
  - 24-C to fire two 1E-30 dets for the slapper x-unit shock switches triggered at 79.908 µs
  - SIM and streak camera trigger at 89.002, and additional delays were set for streak camera trigger and the individual SIM camera frames as indicated on the data below.
- PDV trigger sent out at 80 µs. PDV data below is corrected for transit time to and from the Trailer Bay where the PDV were recorded

CVR data for LA-43-S-CT

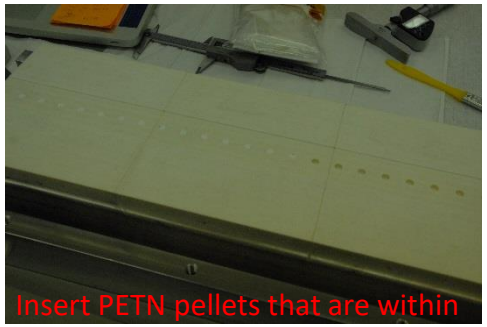
- X-unit trigger
  - Point 88 x-unit 24-C trigger breaks off the baseline at 79.908 µs.
  - 24-C fires two 1E-30 detonators to fire shock switch. It was not recorded what length cable, but they were either 60 or 90 feet.
- Slapper x-unit load ring occurs at 82.644 µs.
- Peak current 19.1 kA
- Burst time (chosen to be position of arrow on figure) is at 17.8 KA and 82.806 µs.



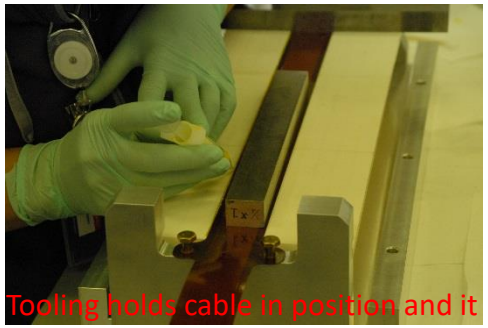


Charge preparation involved many steps

Join three half cylinders



Insert PETN pellets that are within -0.002” to + 0” at counter-bore top



Tooling holds cable in position and it is glued in place and sealed

Aralhex adhesive is applied and smoothed to sub 1 mil thickness

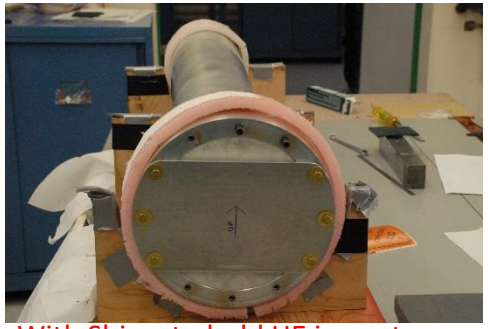
Tooling locates half cylinder ends and light pressure adjusts gap to a minimum at all locations

Two segments of the bell are glued

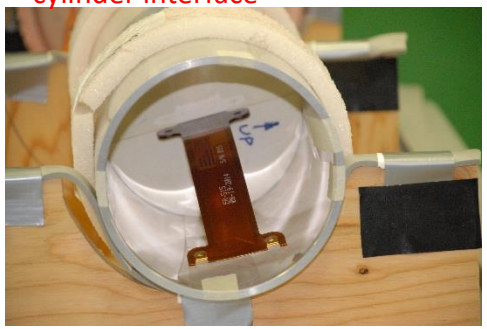
Top half of the tooling is removed here, but careful adjustment provided good glue joint at bell / cylinder interface

Excess adhesive is trimmed

HE placed bell end down and armature lowered onto it. Armature re-positioned bell-side up and HE justified itself on swoop.



With Shims to hold HE in center, Plate with rubber gasket installed to keep HE justified against swoop

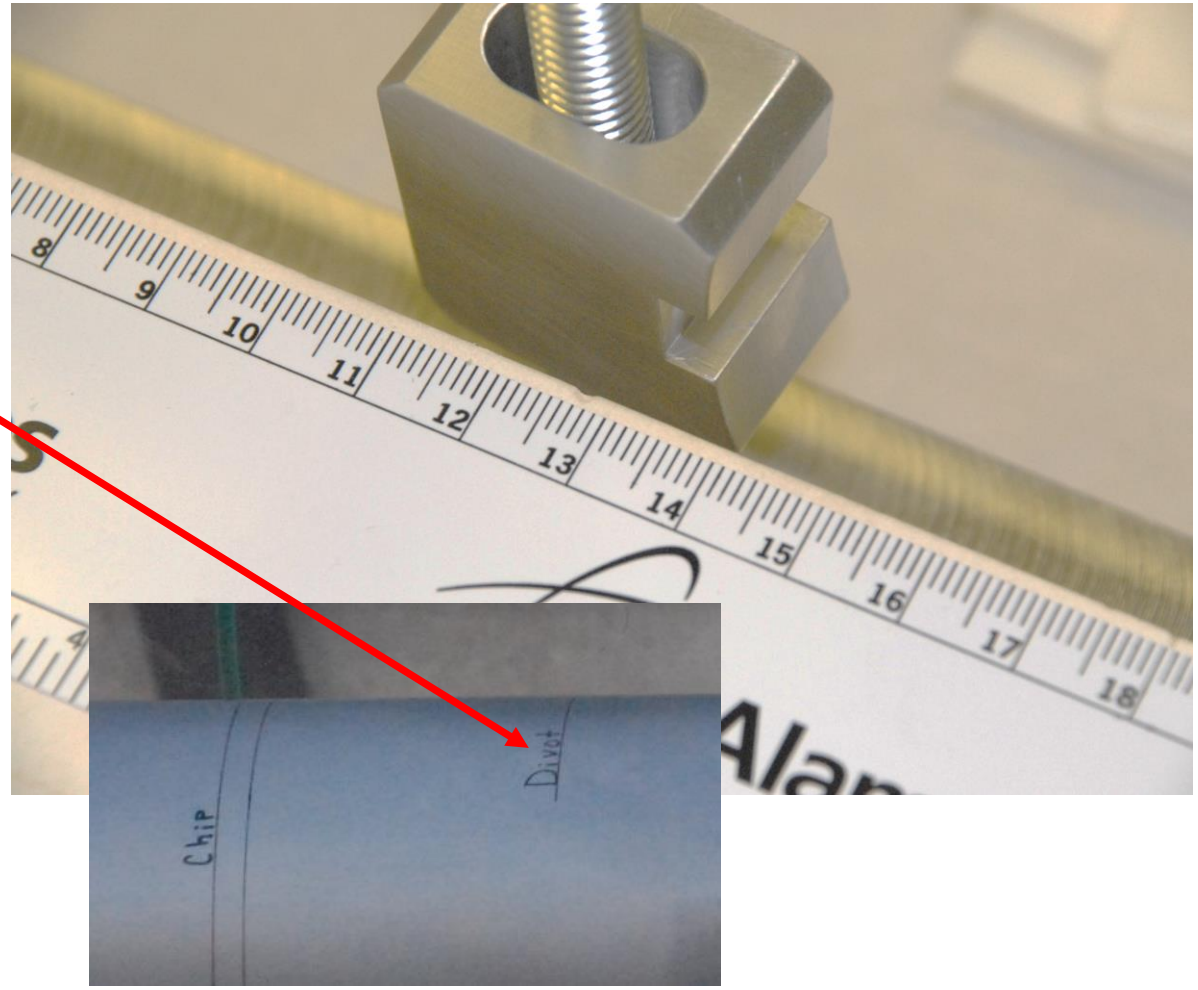


HE orientation maintained so joints and flaws will be seen in camera record

G-10 plate installed and sealed as it will be for pulsed power shot. Extension cables installed.

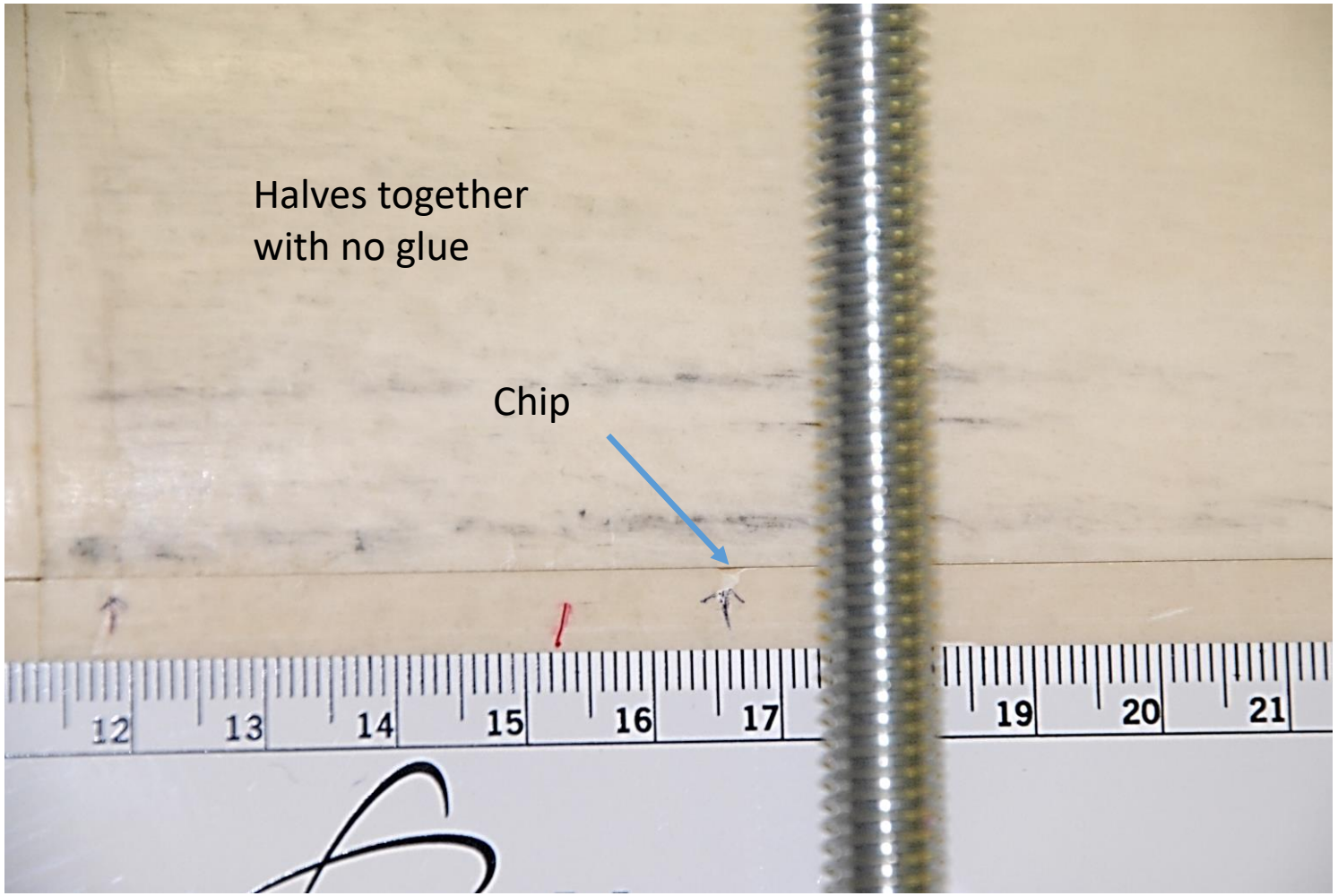
We had a serious “divot” along one joint

- Divot seen here between ~12.6 and 12.8 mm is believed to be a place where one of the pressing “prills” chipped out during machining.
- The location of the divot was specifically marked on the armature before the test.
- The adhesive used to glue the two HE halves together essentially filled the divot, and no further effort was made to fill it.
- No bad effect was seen on the camera record



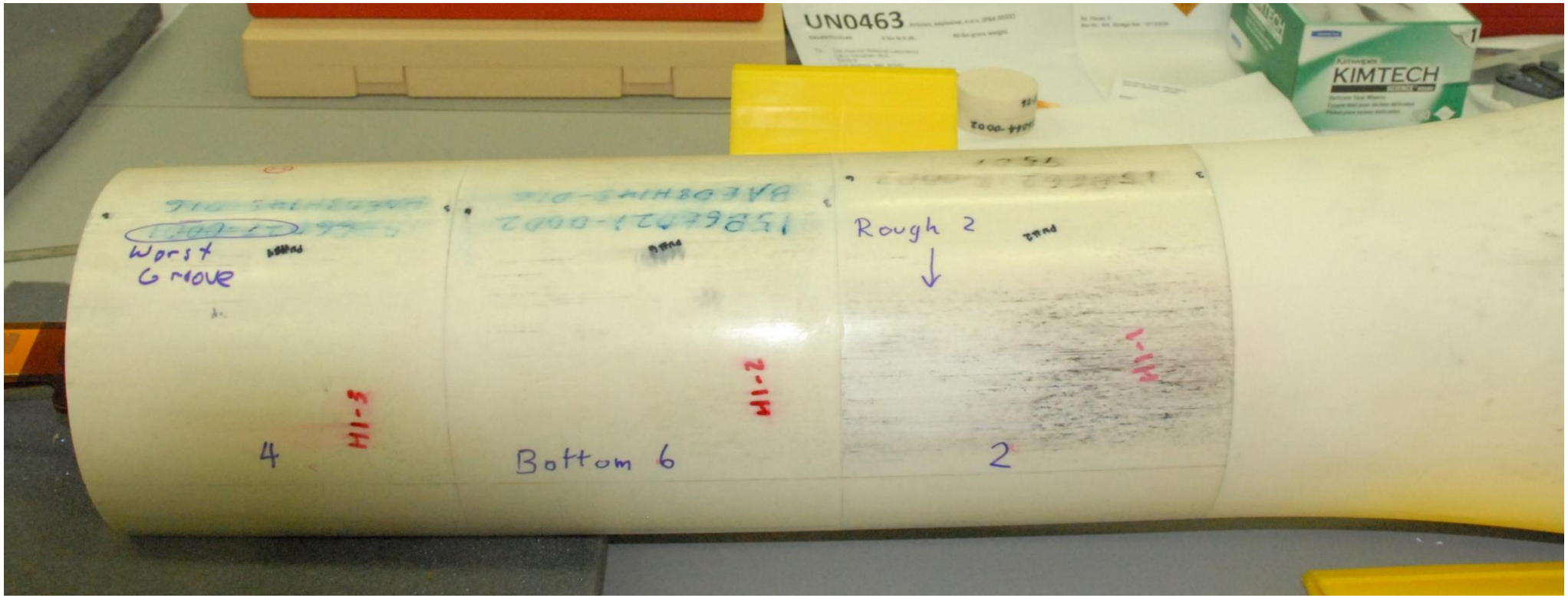
One chip occurred at a seam

- The location of the chip was specifically marked on the armature before the test.
- Ultimately the adhesive essentially filled the chip
- No bad effect was seen in the camera record



The “as-pressed” cylindrical charges were rougher than expected

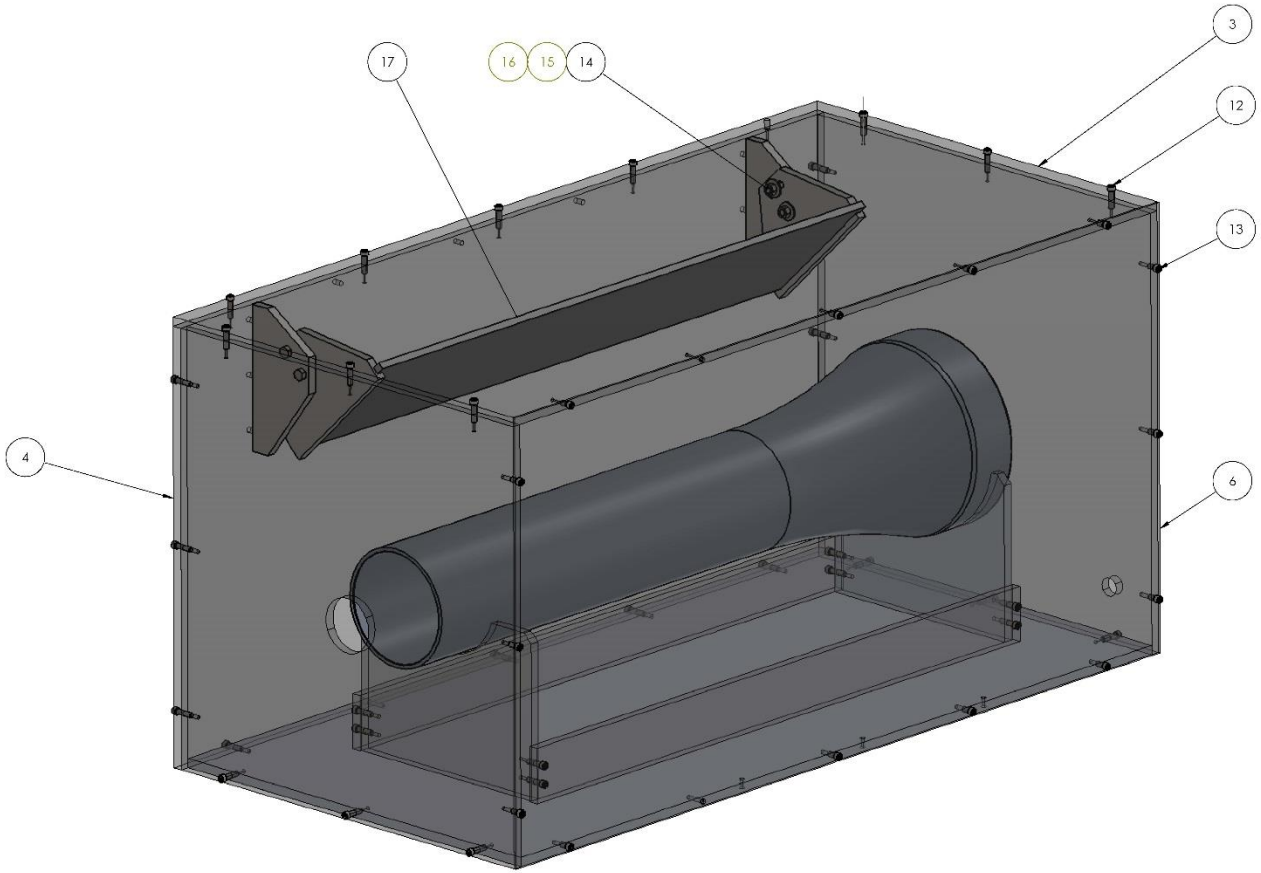
- Significant grooves were found on the as-pressed surfaces.
- The lubricant (black) could be cleaned off, but then the grooves seemed worse
- Many places were noted, but none produced bad effects in the dynamic records

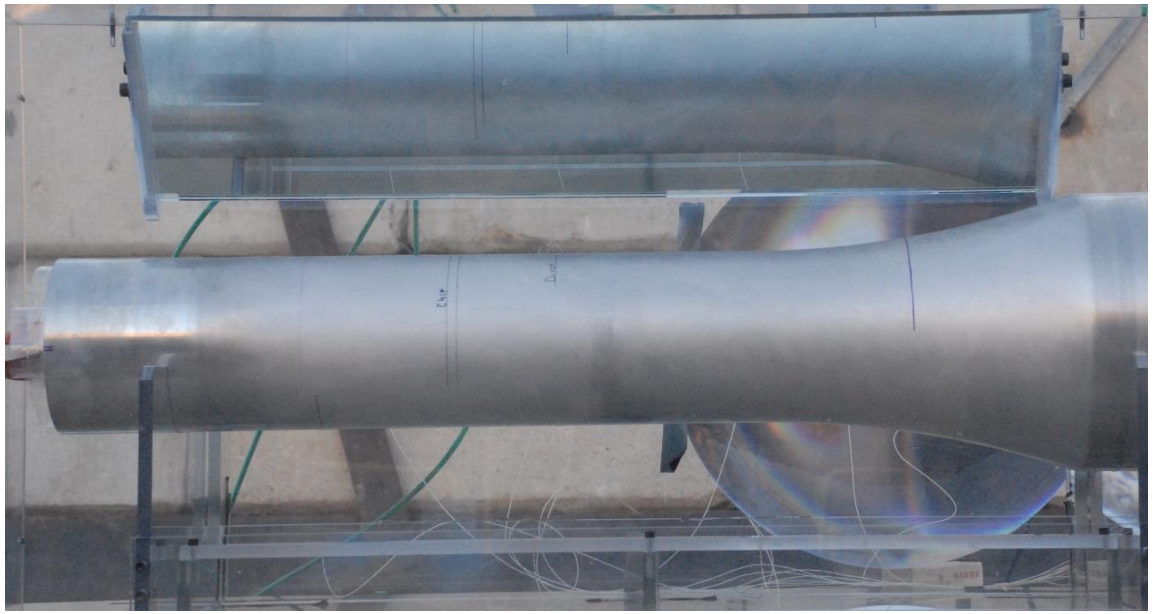


Armature to HE-Fit discussion

- Armature was opened up to 10 mils clearance on radius from previous designs with 5 mil clearance
- HE was 5 mil undersize on diameter (not 6.000” but 5.995”)
- HE positioned on floor and Armature lowered over it.
- 5 mil Mylar shim inserted all the way around, then 5 mils more at 4 sides.
- Armature lifted, then inverted so HE slid to position justifying it on angle of swoop.
- 5 mil feeler gauge inserted on 3 sides, and would not quite go in on fourth.
- Aluminum plate positioned on end with rubber grommets to maintain loading on G-10 disc so that HE was held against the cone.

Shot enclosure provides a helium atmosphere that prevents an air shock from obscuring the surface during expansion. Mirror in shot enclosure also provides backside coverage for ~2X expansion.





Front wall is thin polycarbonate/ all other walls are ½” polycarbonate


End view of setup showing Polycarbonate box to hold He which prevents an air shock from developing and obscuring the expanding surface.
Mirror
Flash at 31.8 (.213 on Phantom) is from hitting probe support which was located at the 2X expansion position
HIGH VOLTAGE INPUT
HIGH VOLTAGE MONITOR

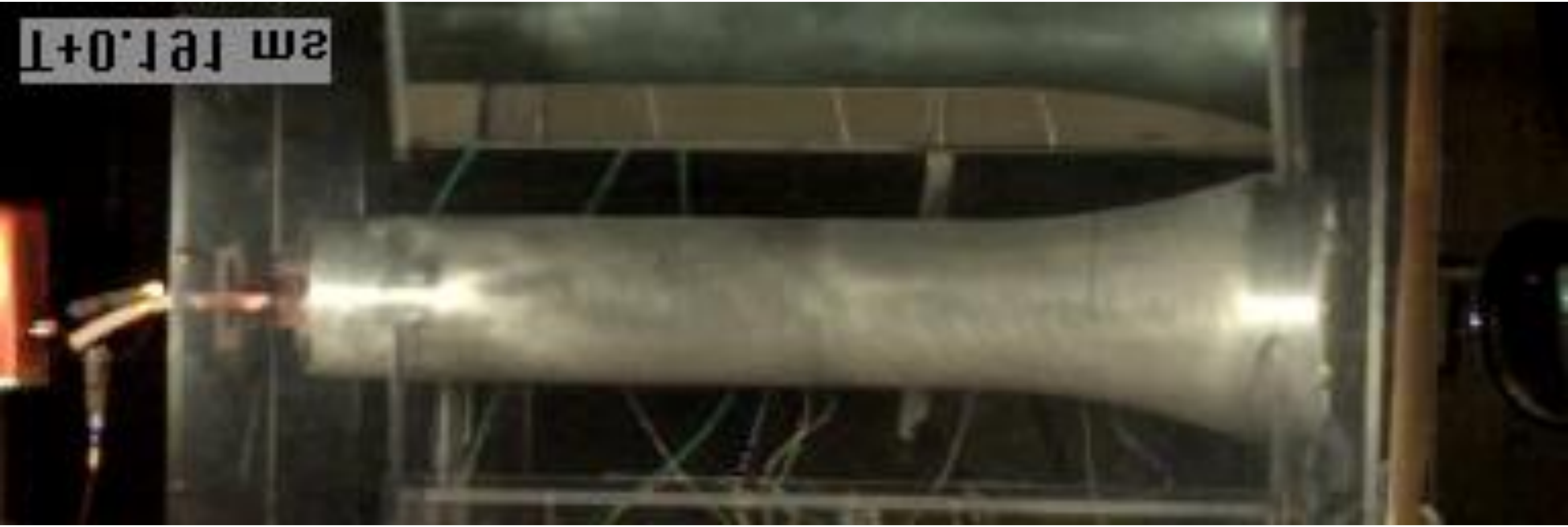
Camera Data - Phantom

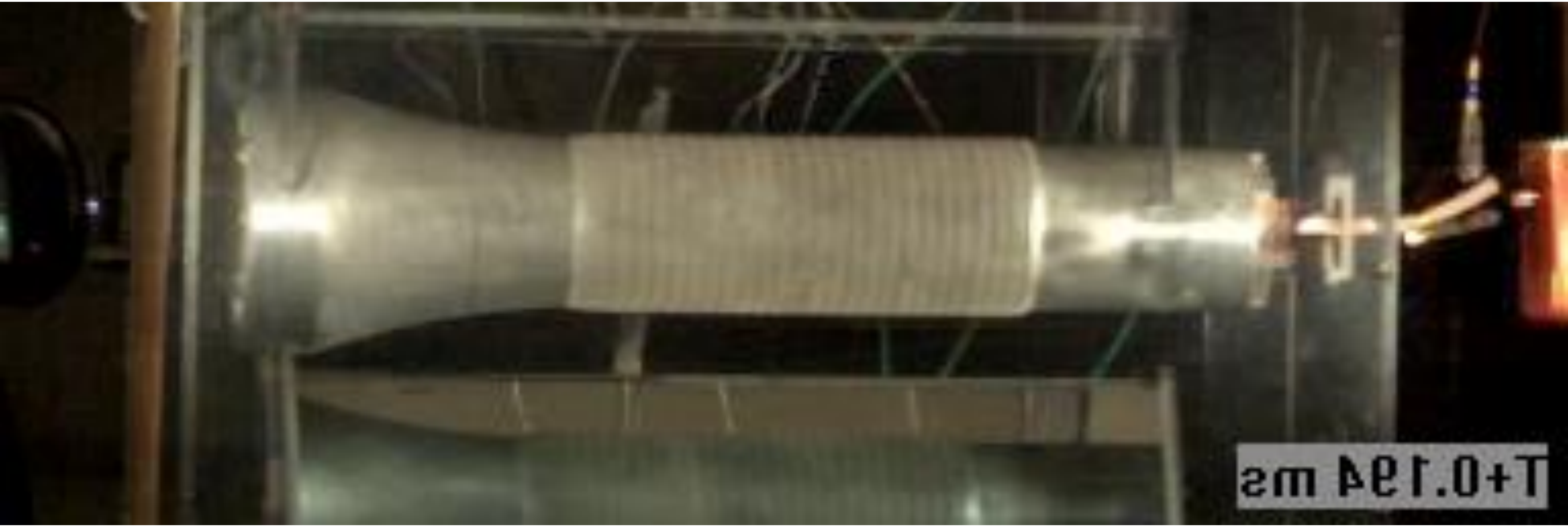
- The images are inverted here so that the shot appears as it did on the firing point
- Frames are at arbitrary times
  - Start here at 0.182 ms
  - 30 ns apart
  - 2X expansion is at 0.213 ms. That frame shows two boxes each sized to be the initial diameter of the armature. It also shows the flash caused by hitting the PDV fiber holder which was positioned at the ~2X position

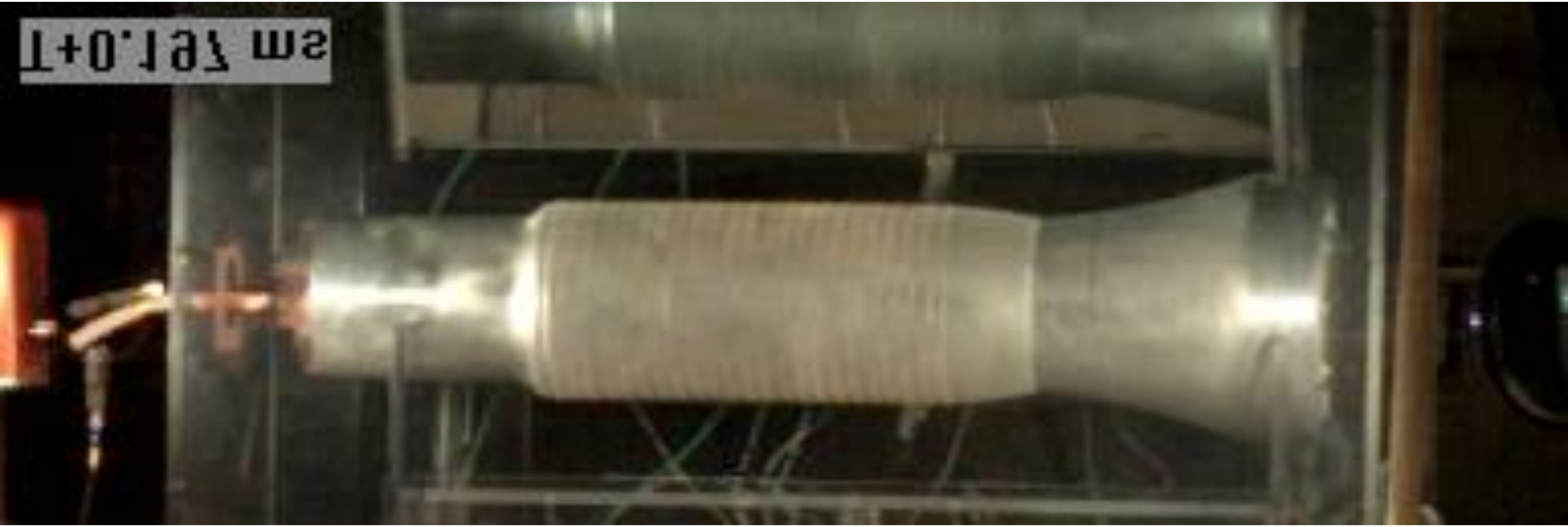

T+0.182 ms

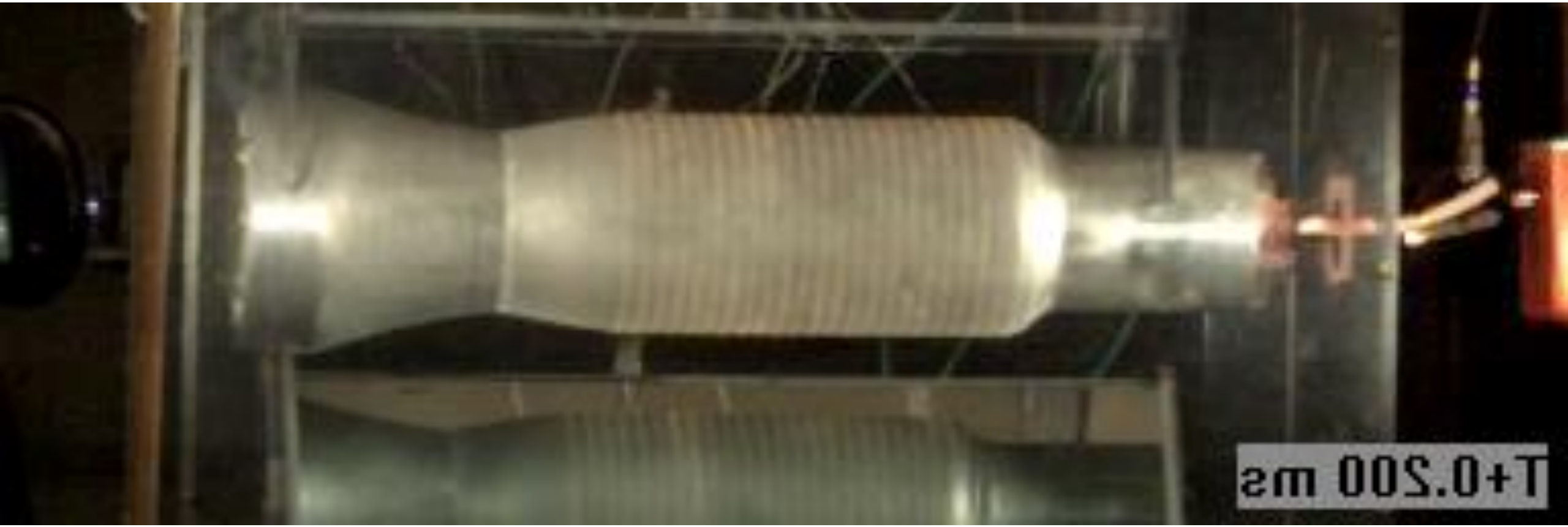

T+0.185 ms

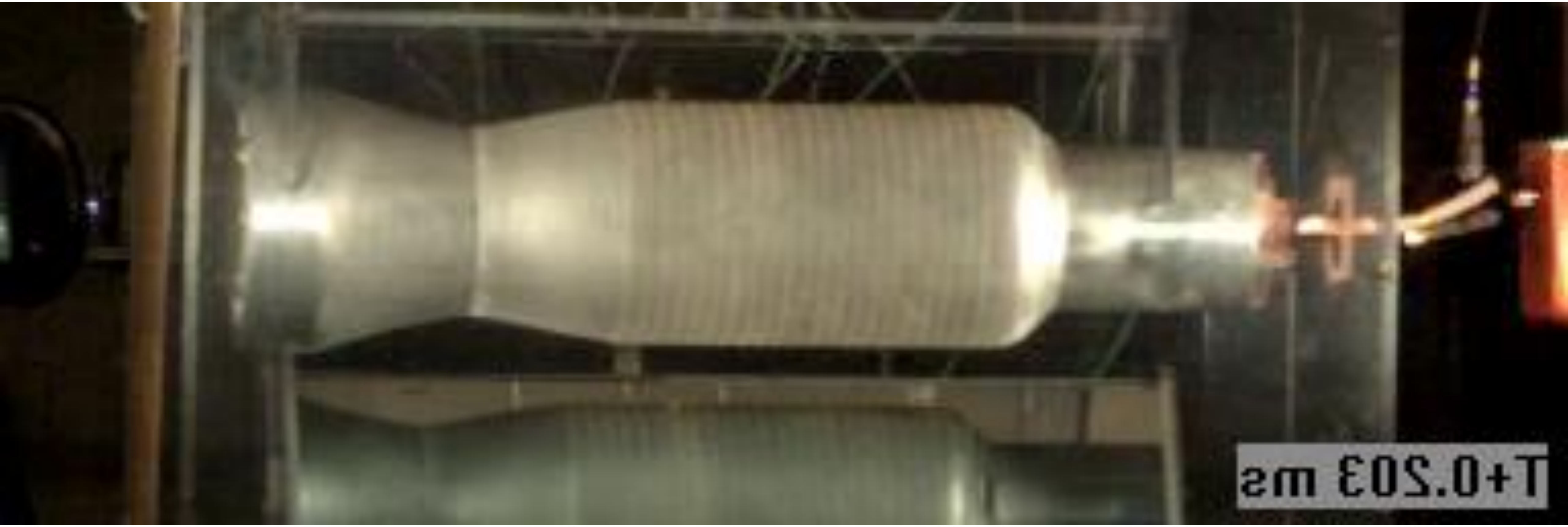

T+0.188 ms


T+0.161 ms


T+0.194 ms


T+0.197 ms

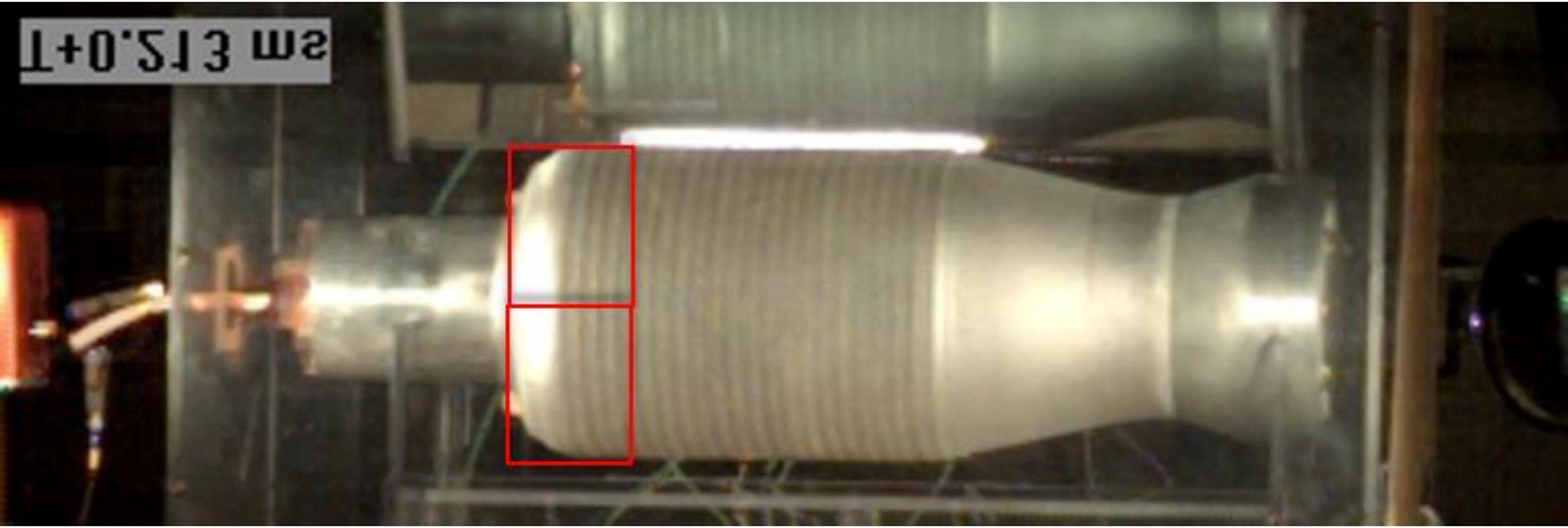

T+0.200 ms


T+0.203 ms


T+0.207 ms


T+0.210 ms

Flash on upper backside is when armature hits PDV holder bracket. Red boxes are ~ the initial diameter.
So armature has expanded 2 X in this frame




T+0.216 ms


Blowup of bottom edge

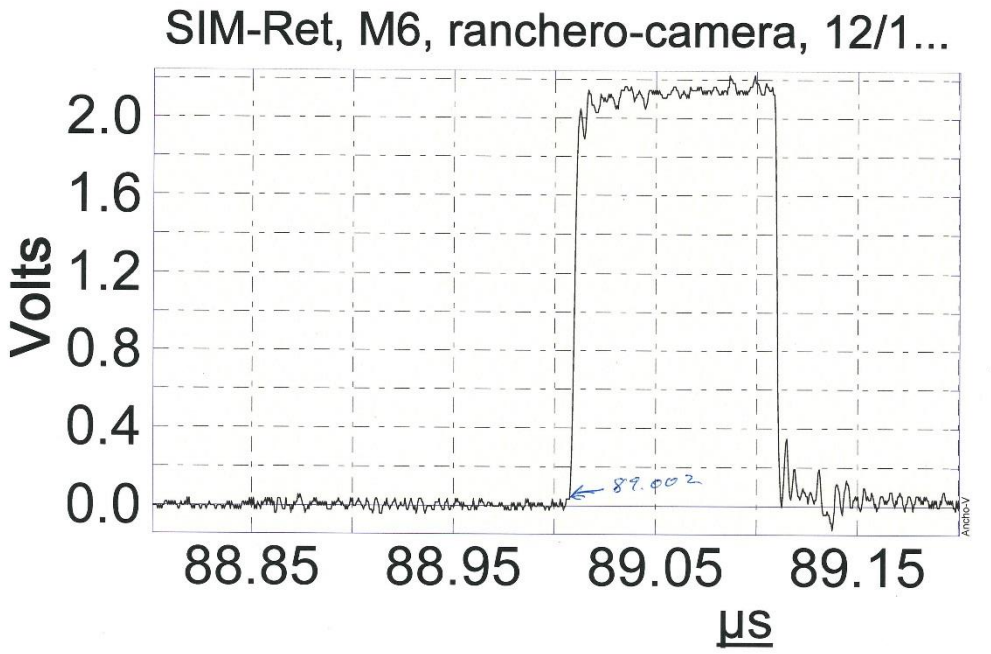

T+0.222 ms

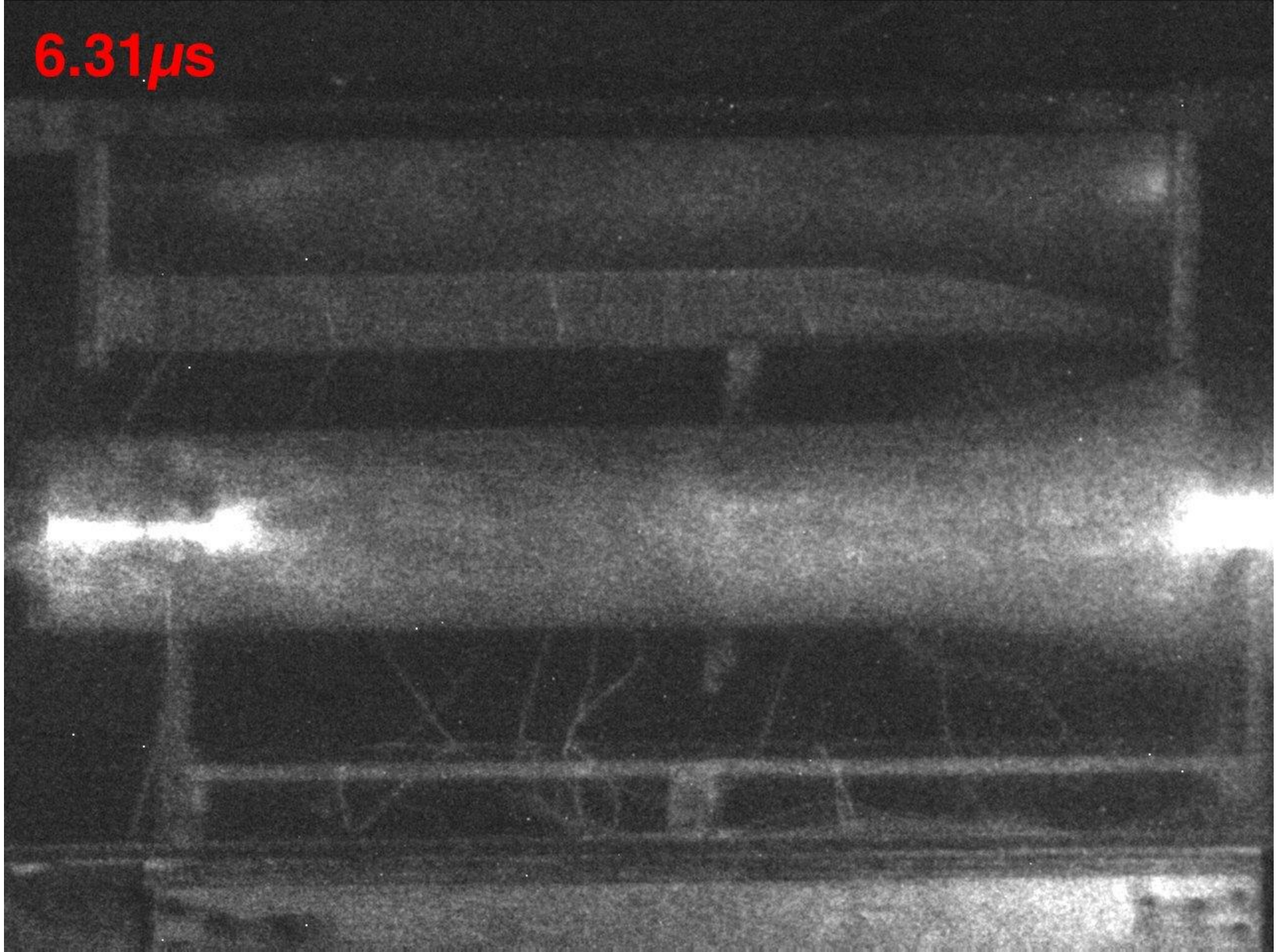

T+0.225 ms


T+0.228 ms

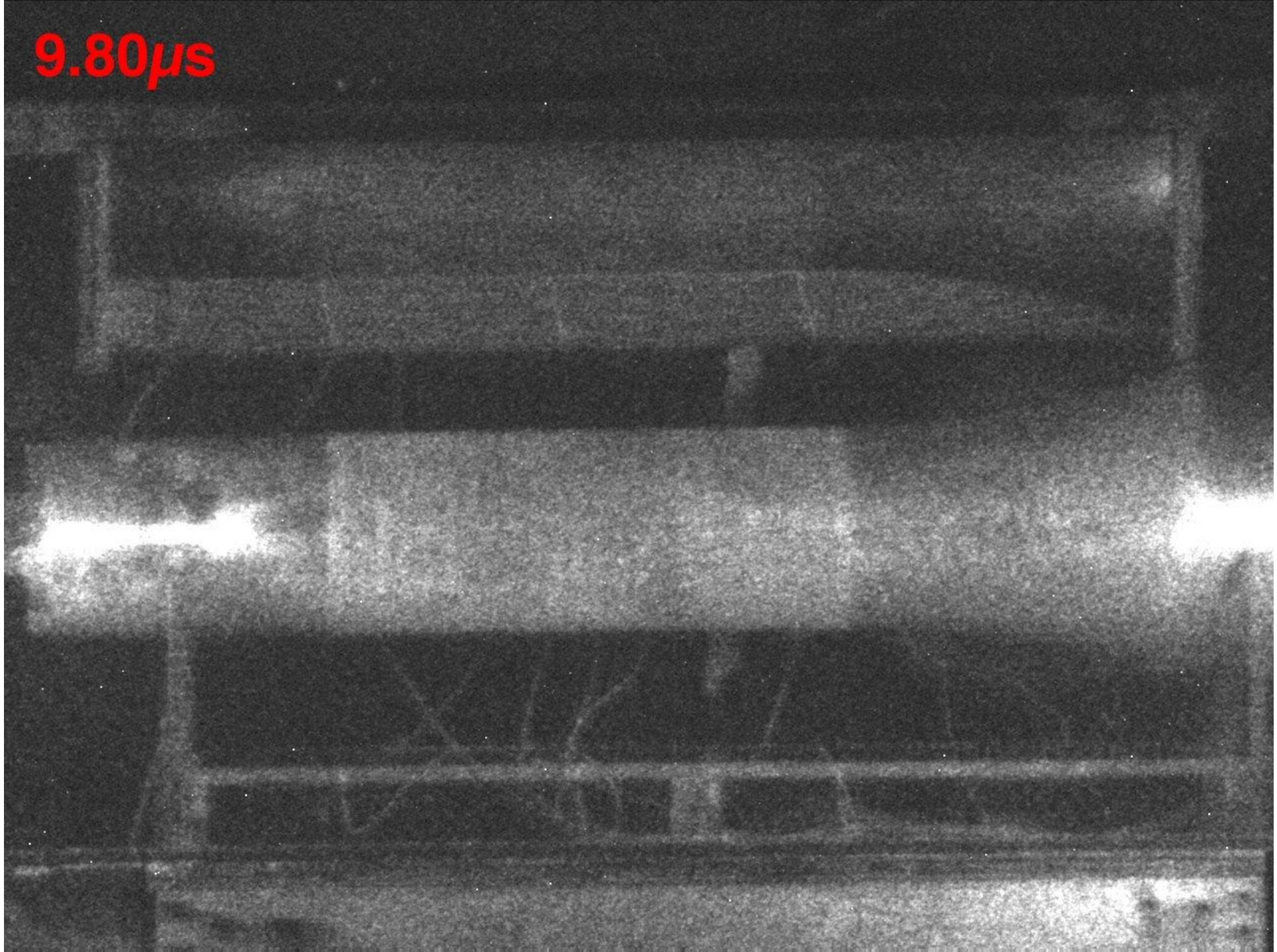
Camera Data - SIM

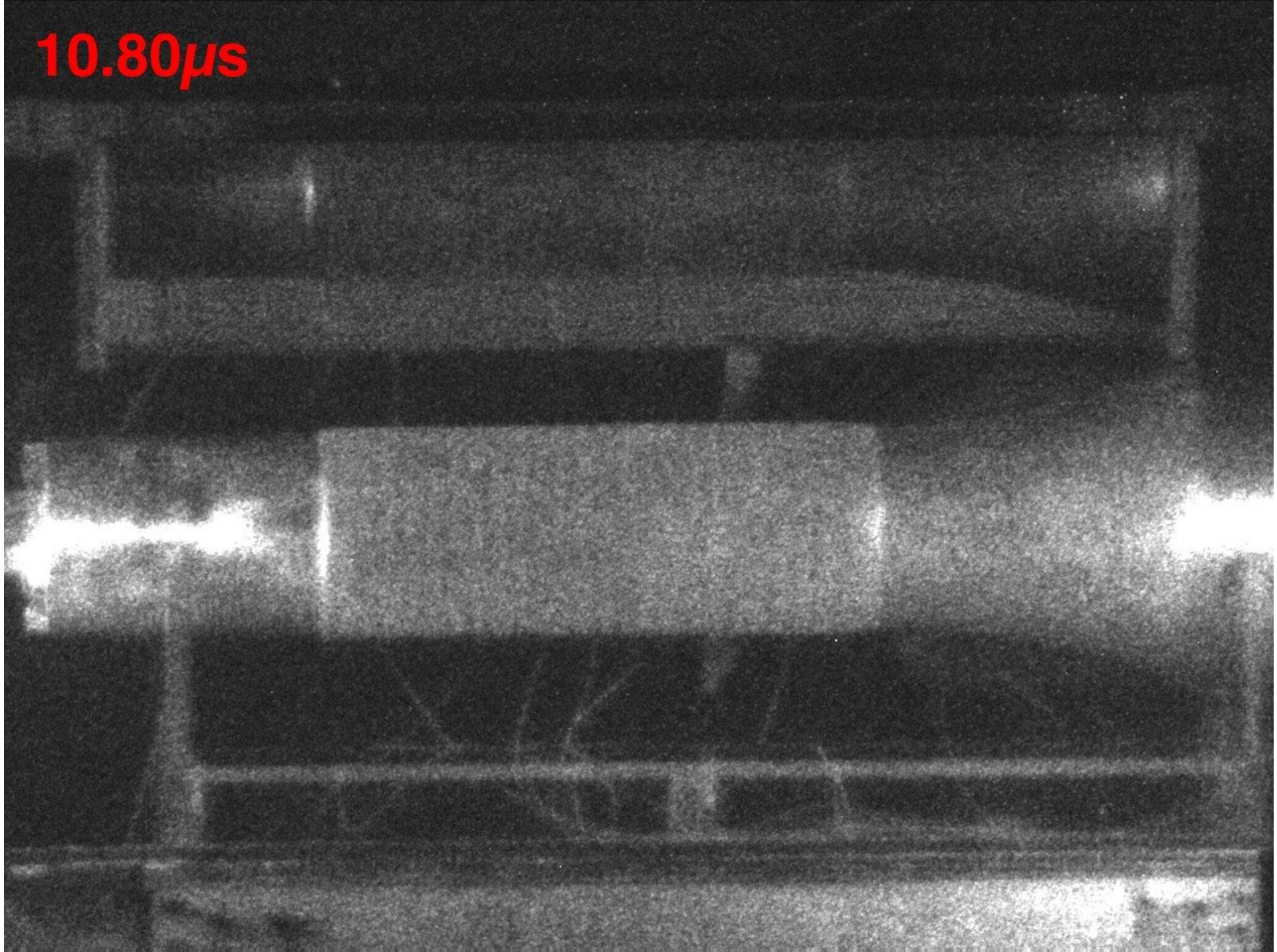
- Frames have the actual times written on them starting from zero at 89.002 µs.

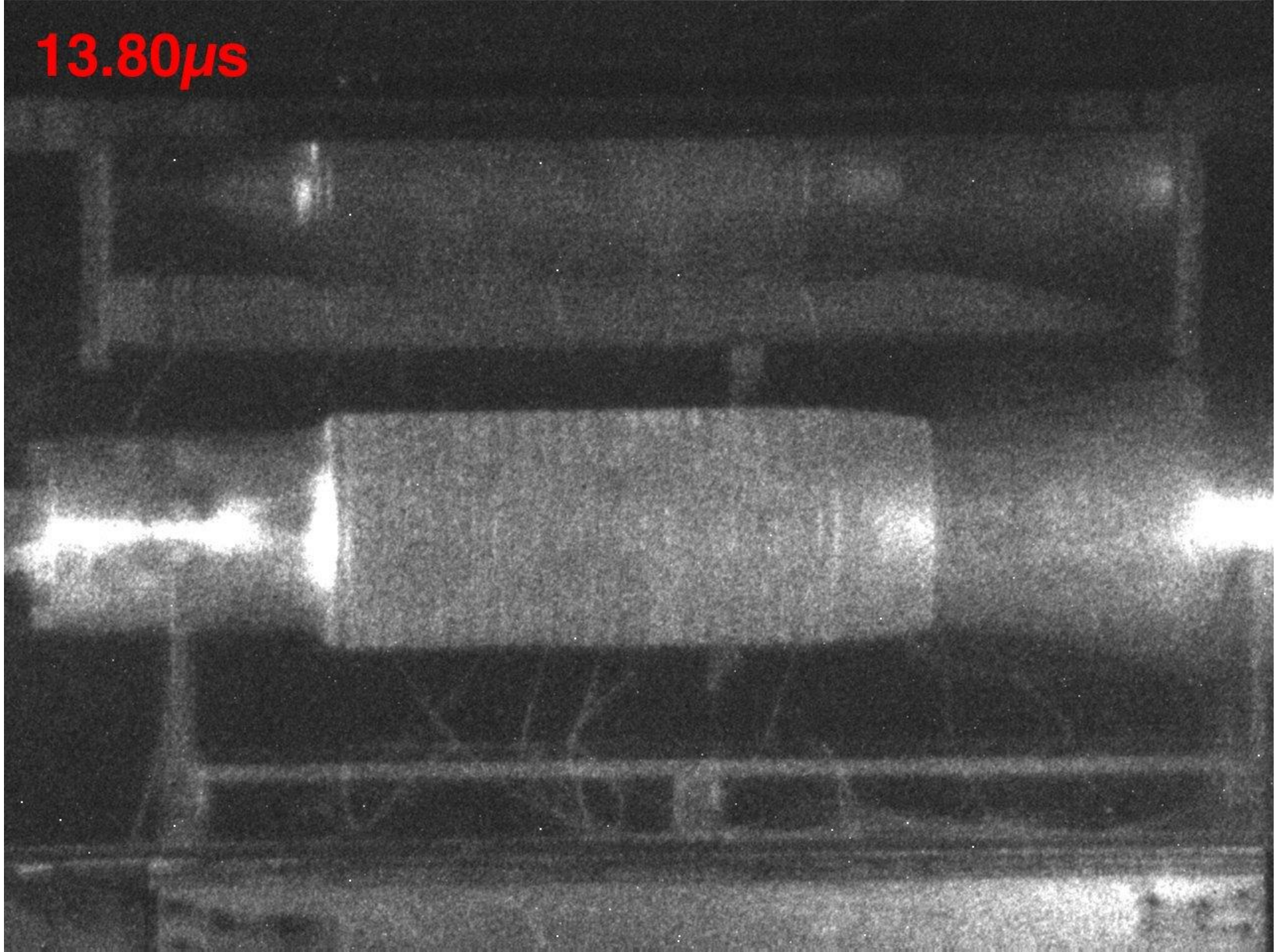


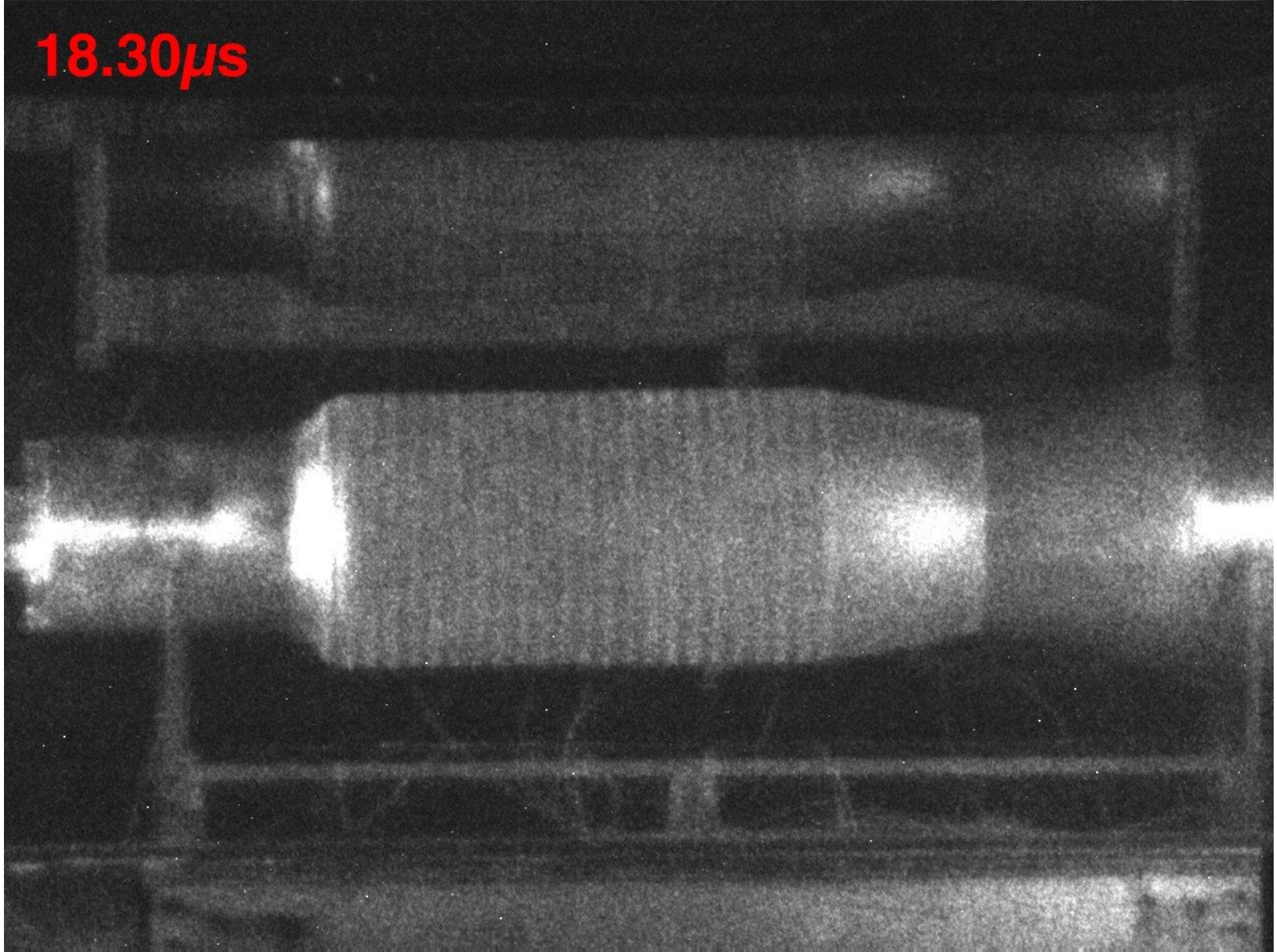

6.31μs

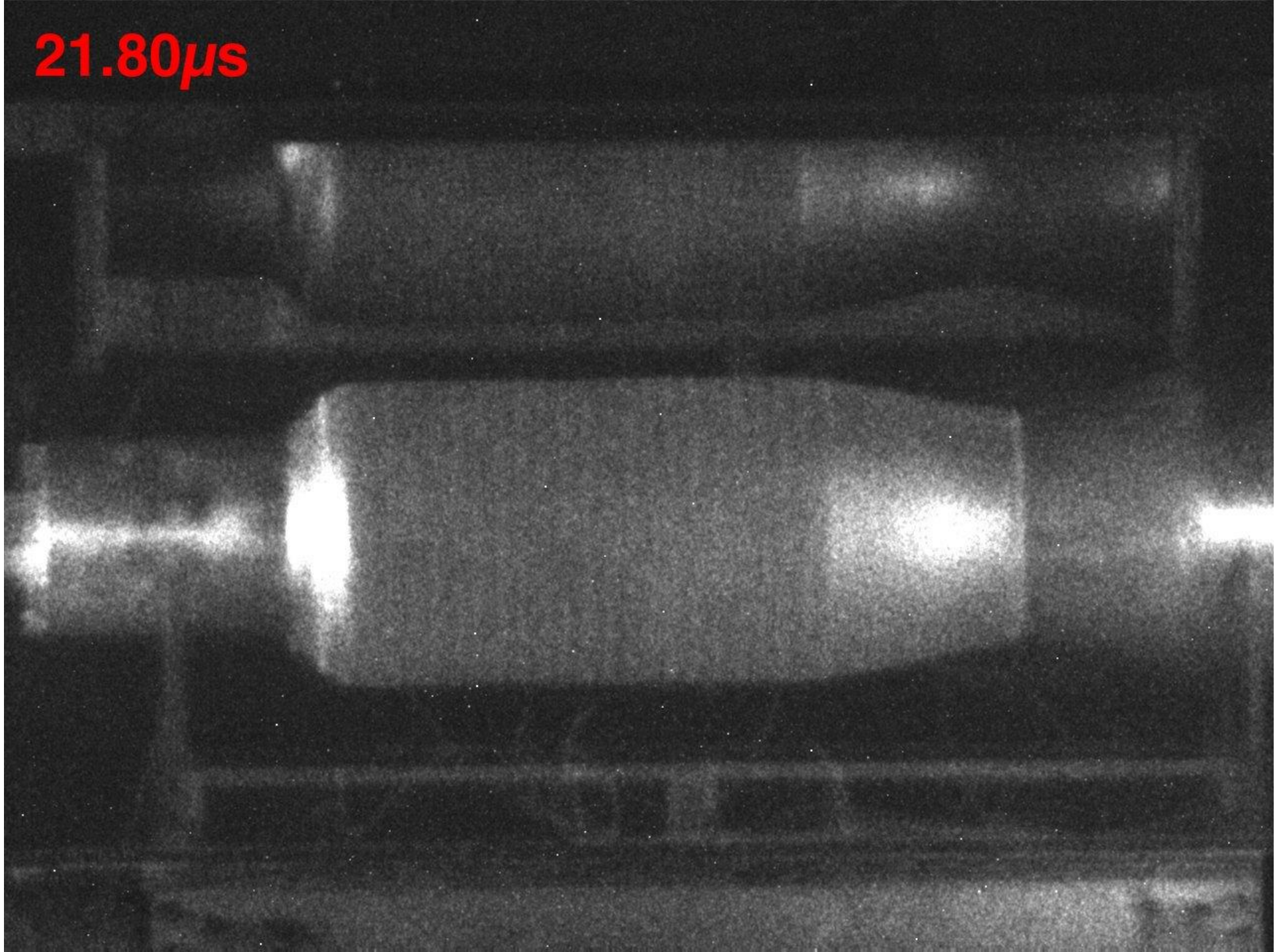

9.30μs

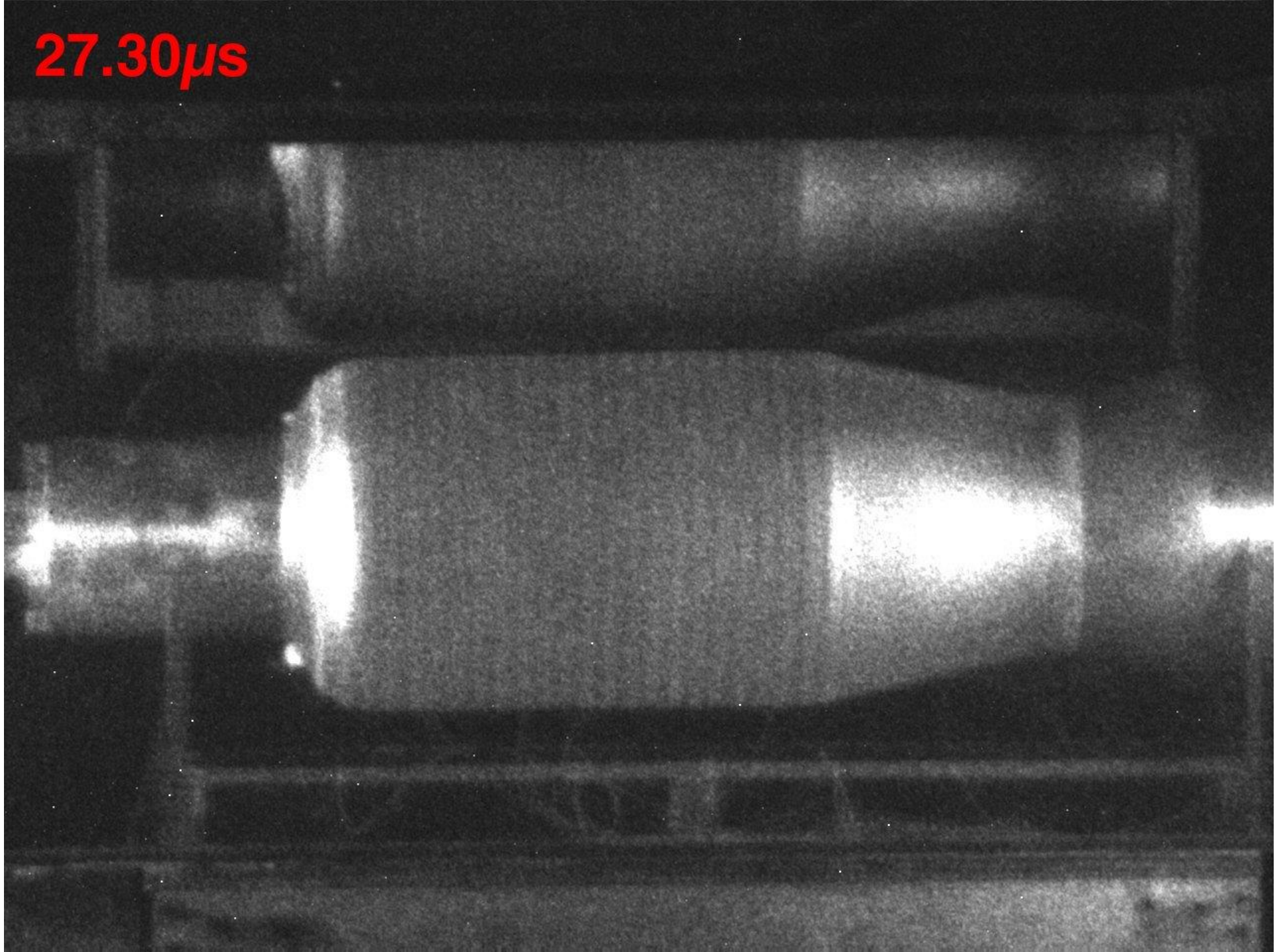

9.80μs

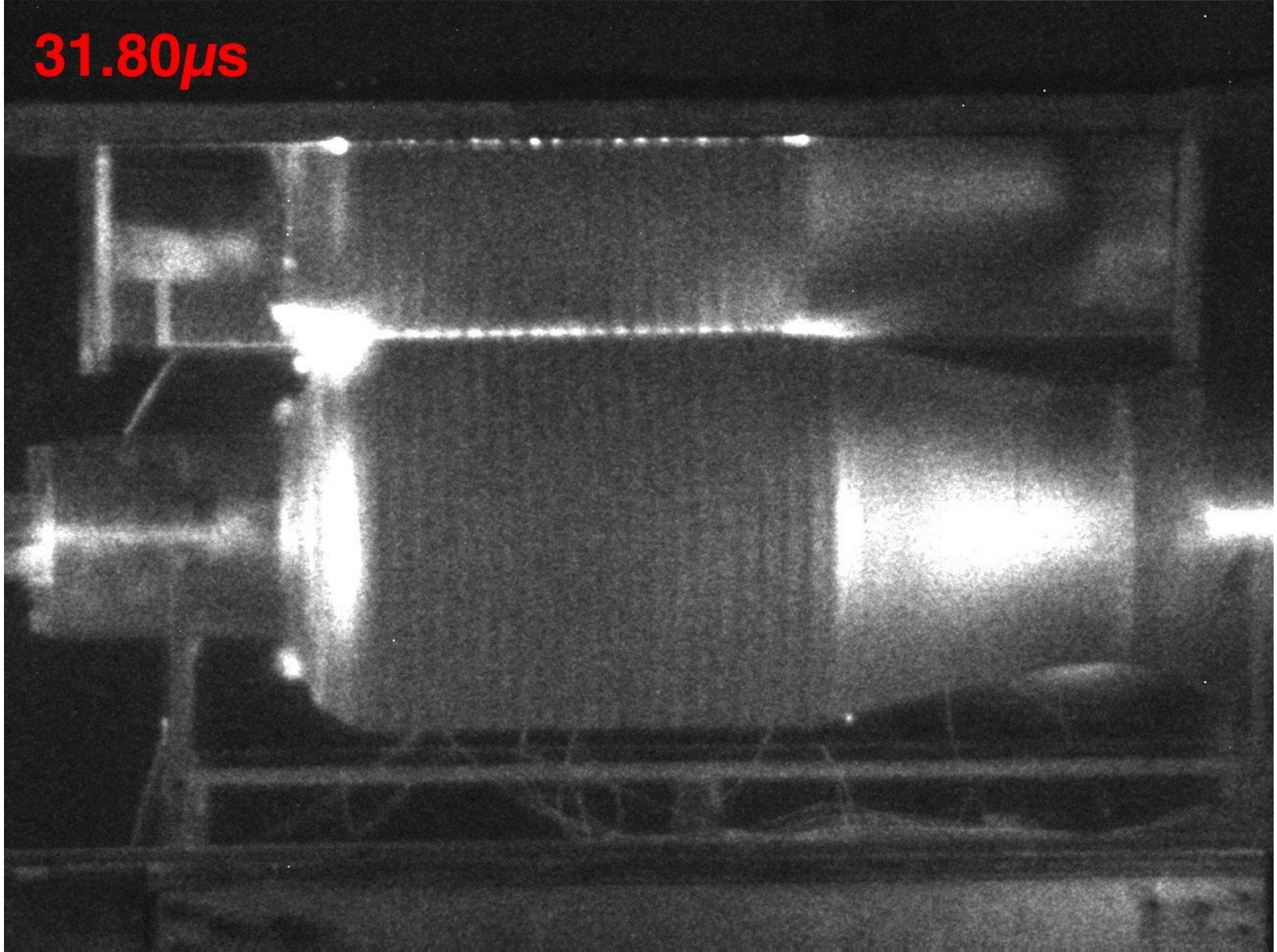

10.80μs

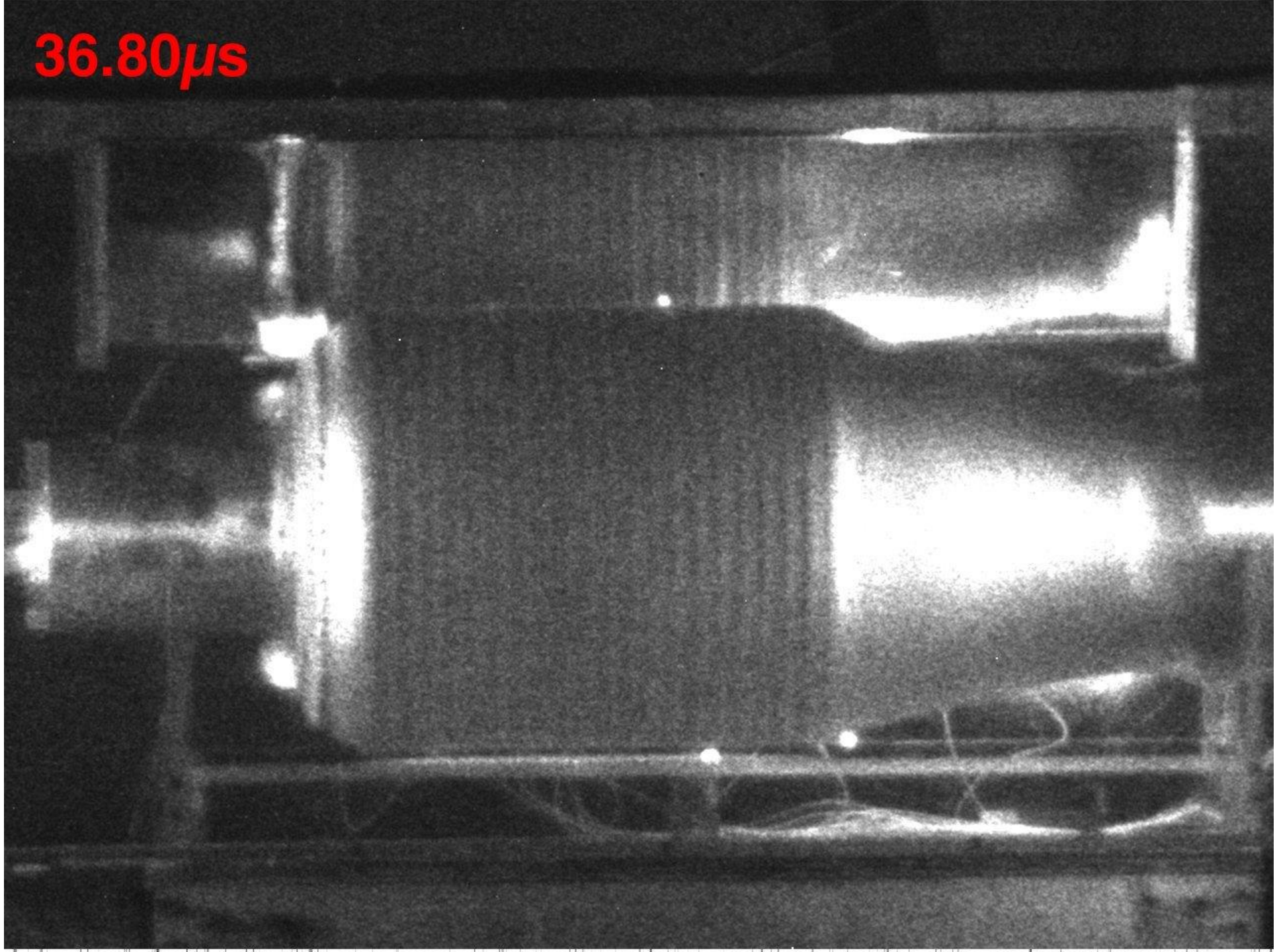

13.80μs

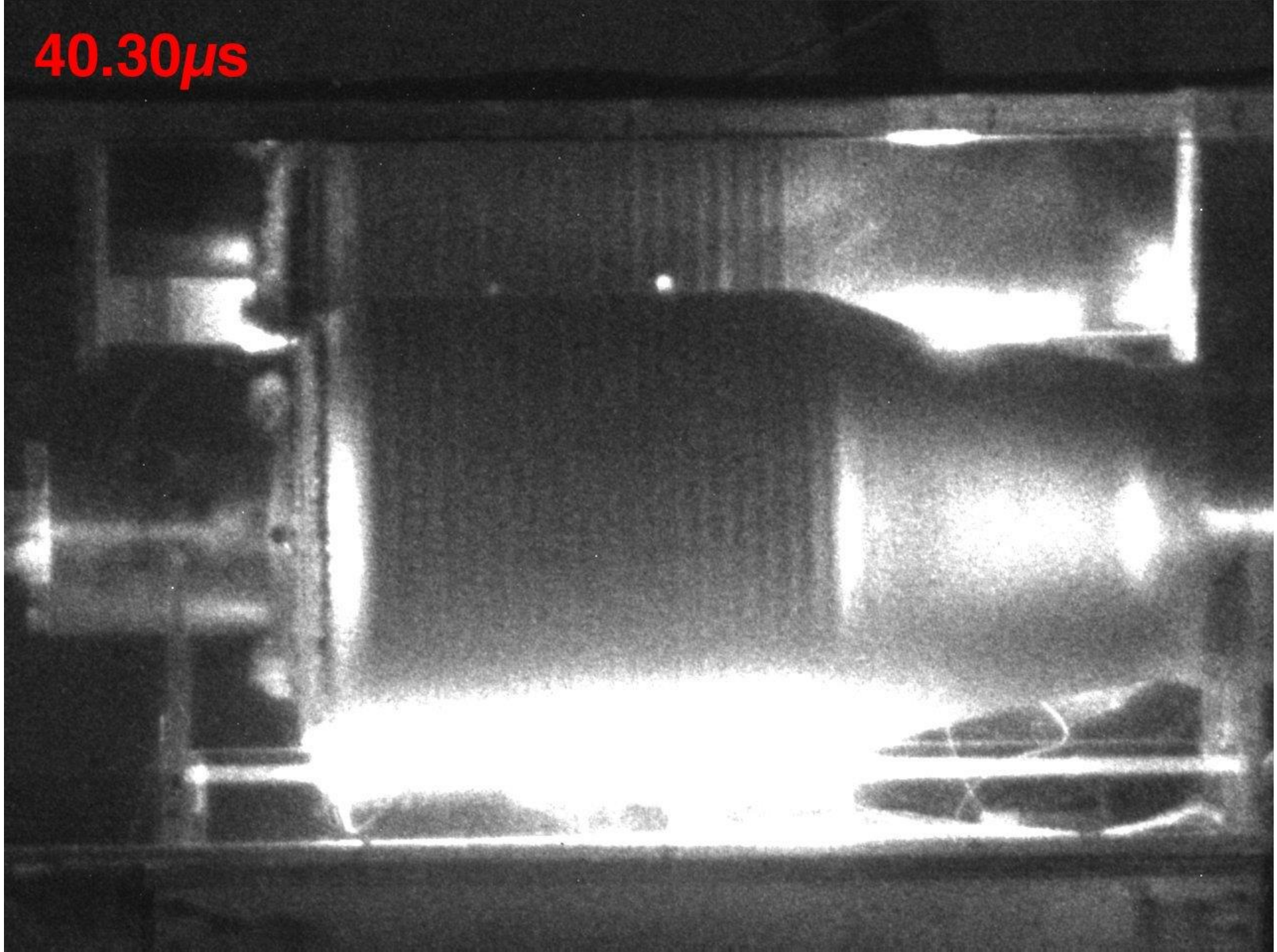

18.30μs

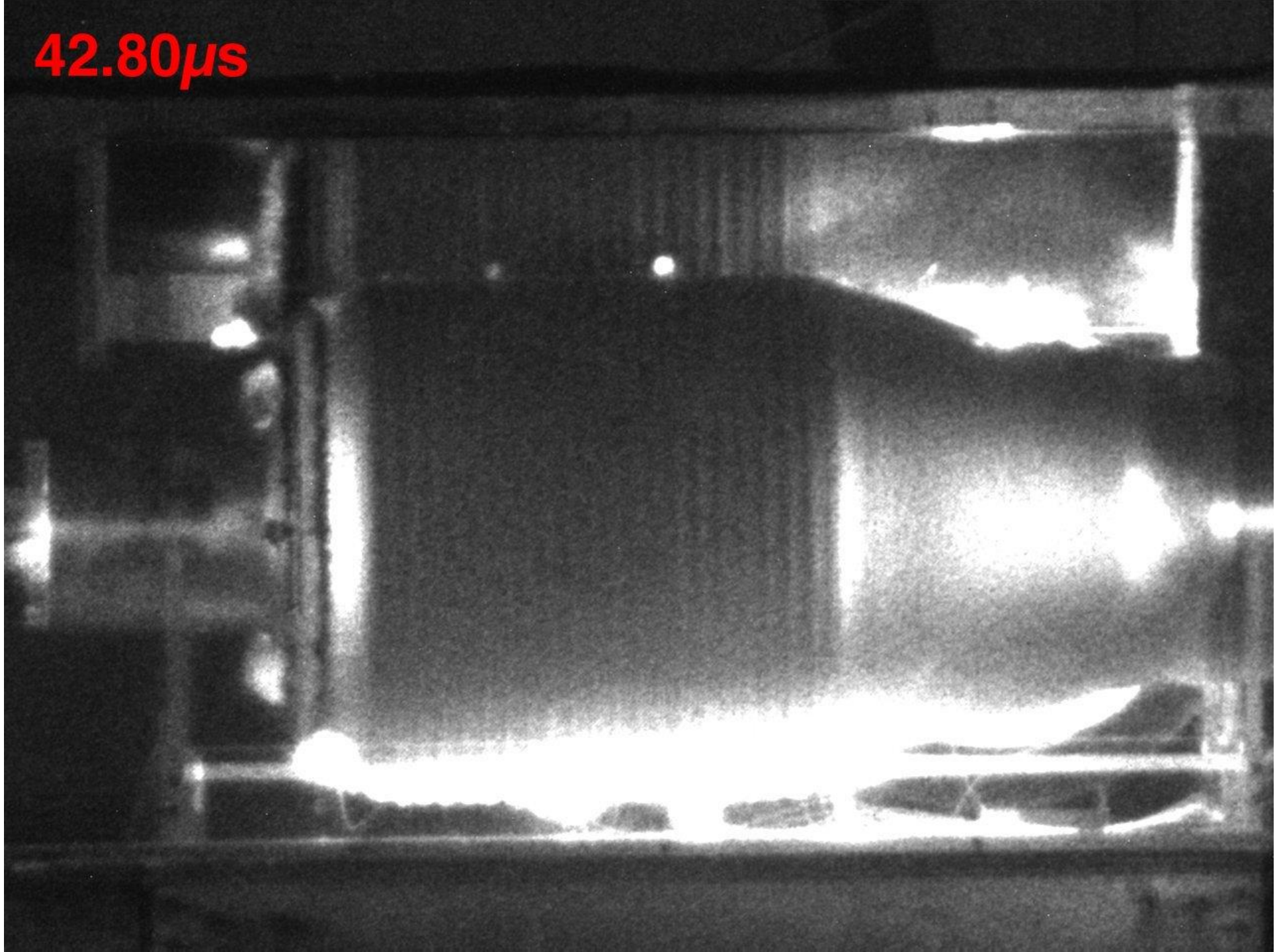

21.80μs

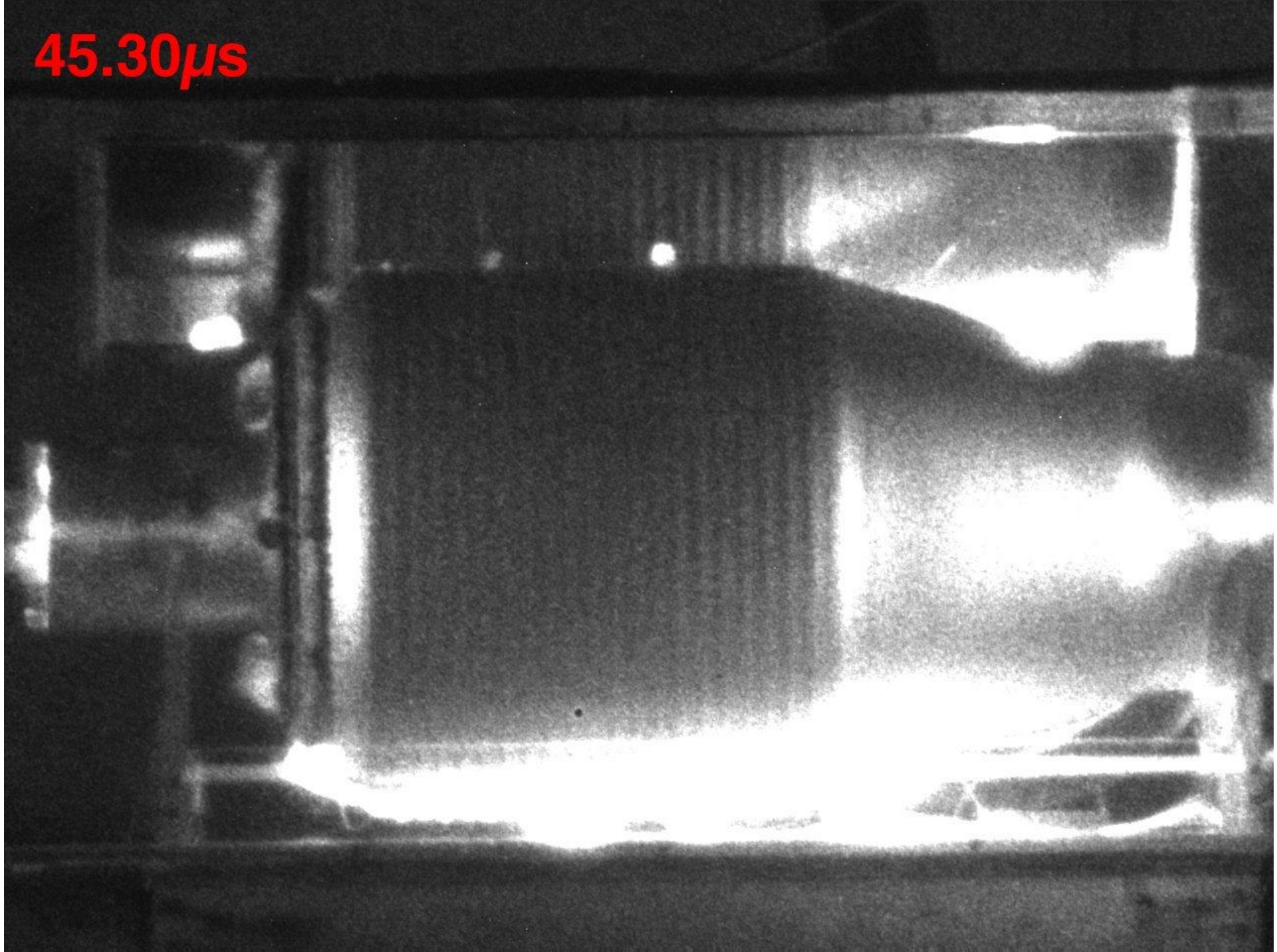

27.30μs

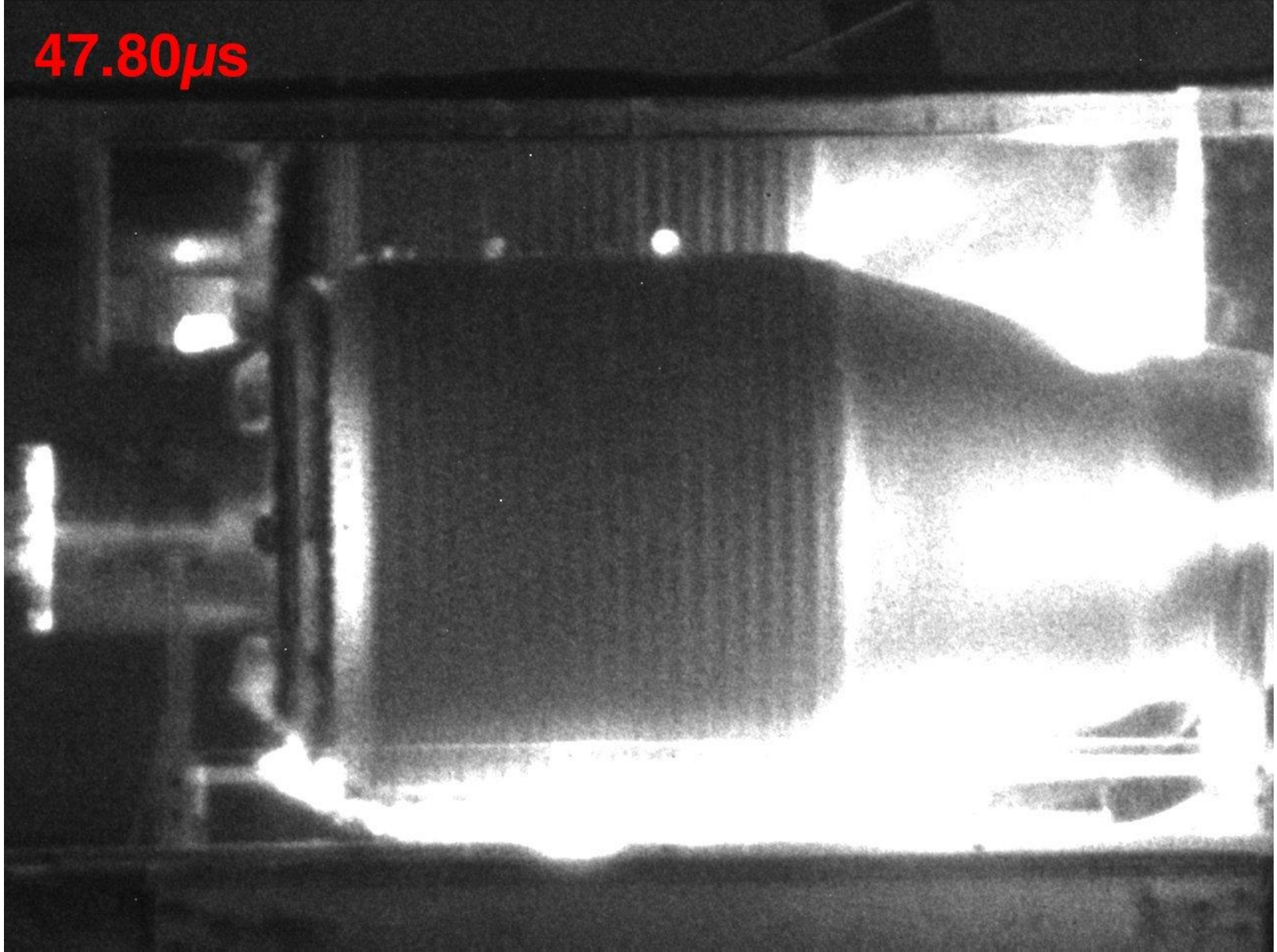

31.80μs

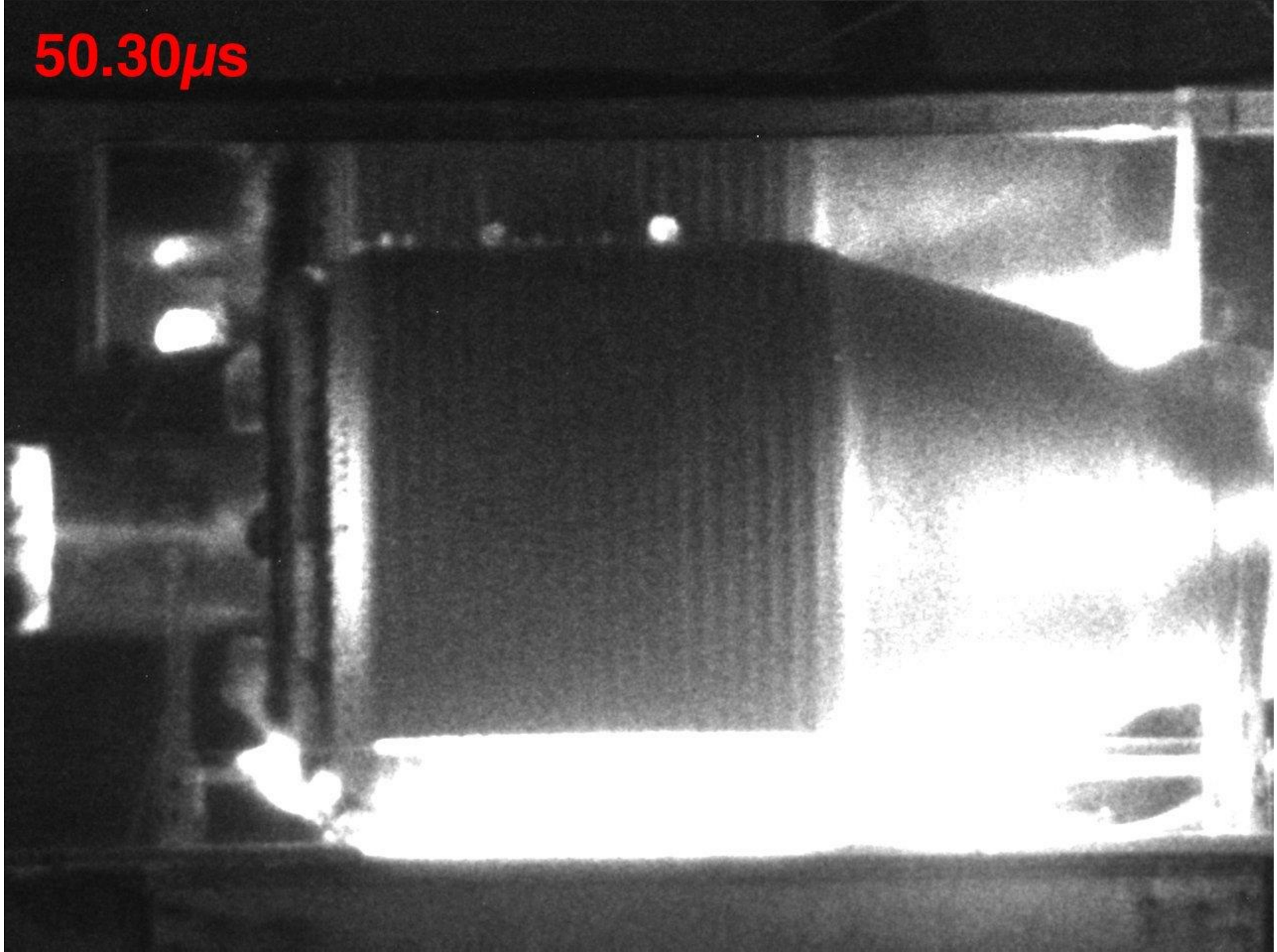

36.80μs

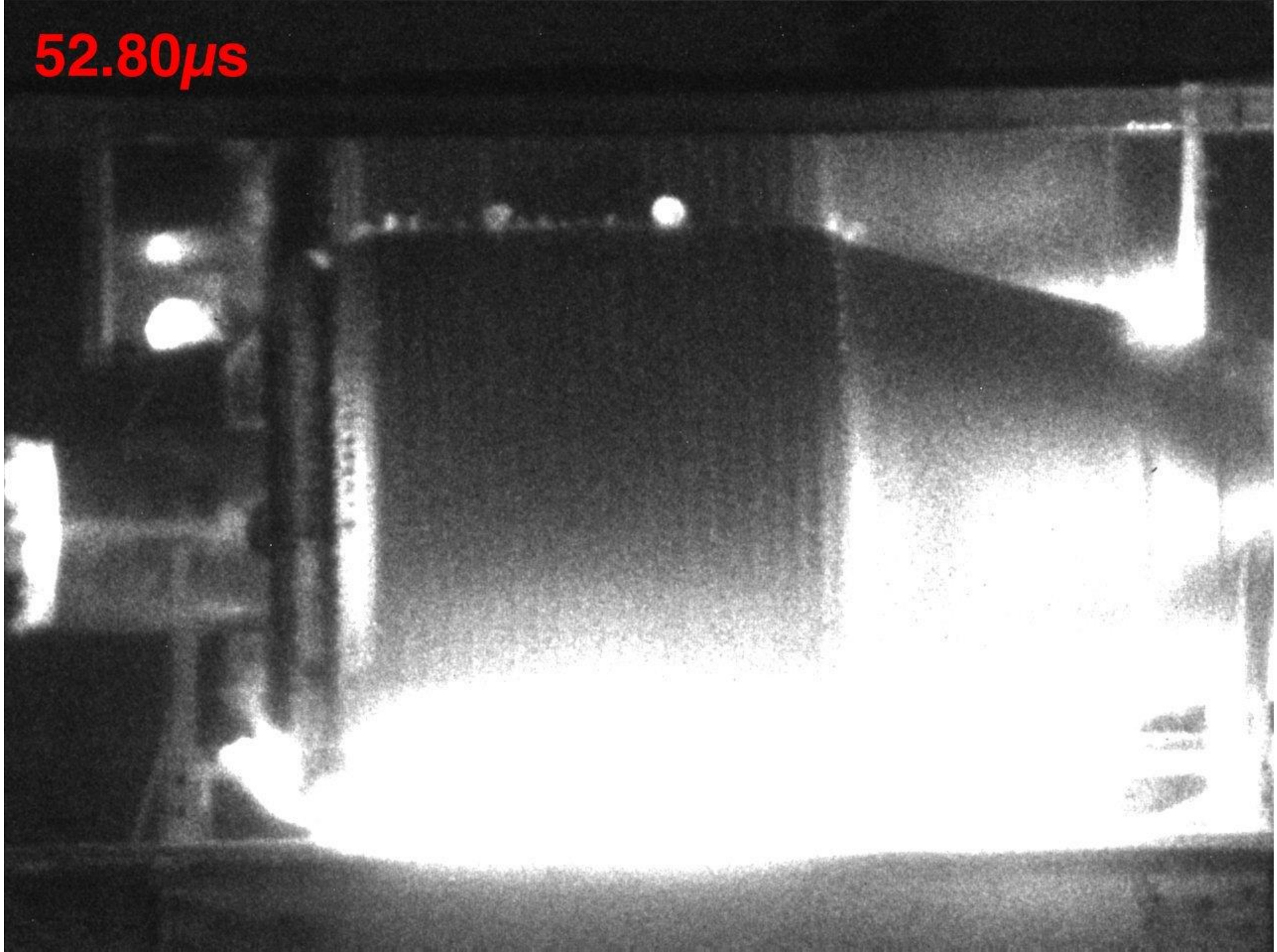

40.30μs


42.80μs


45.30μs

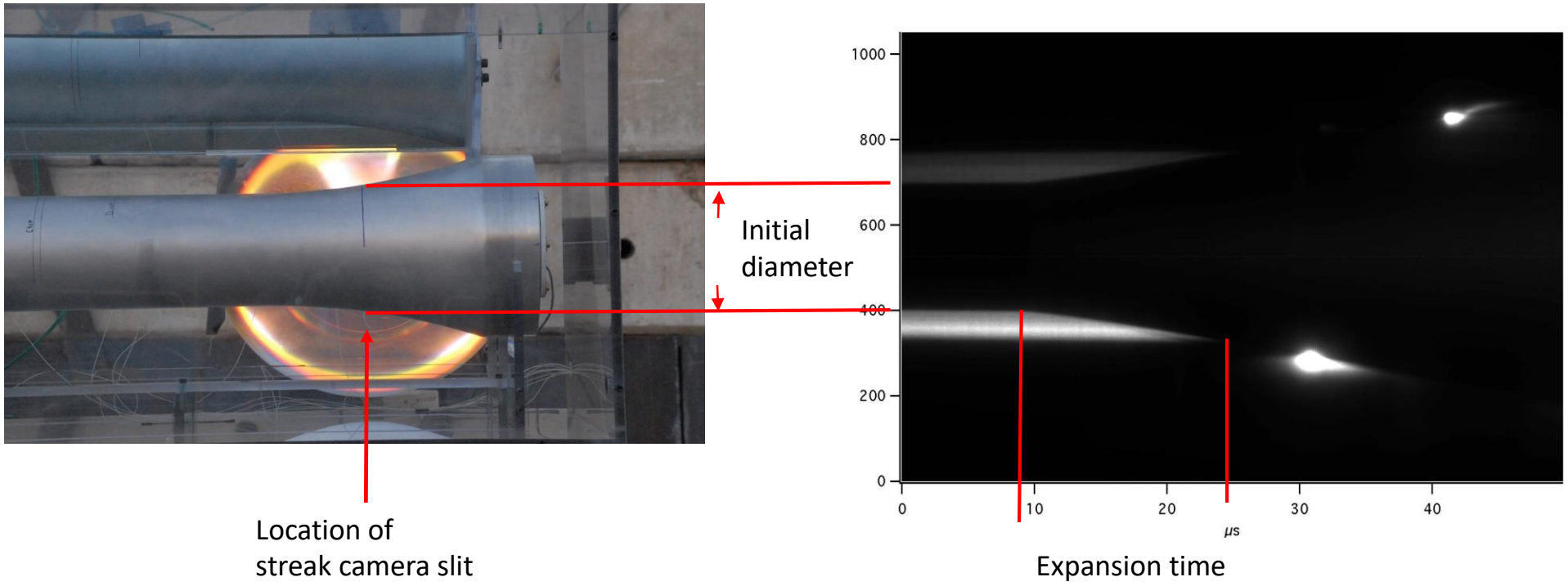

47.80μs


50.30μs

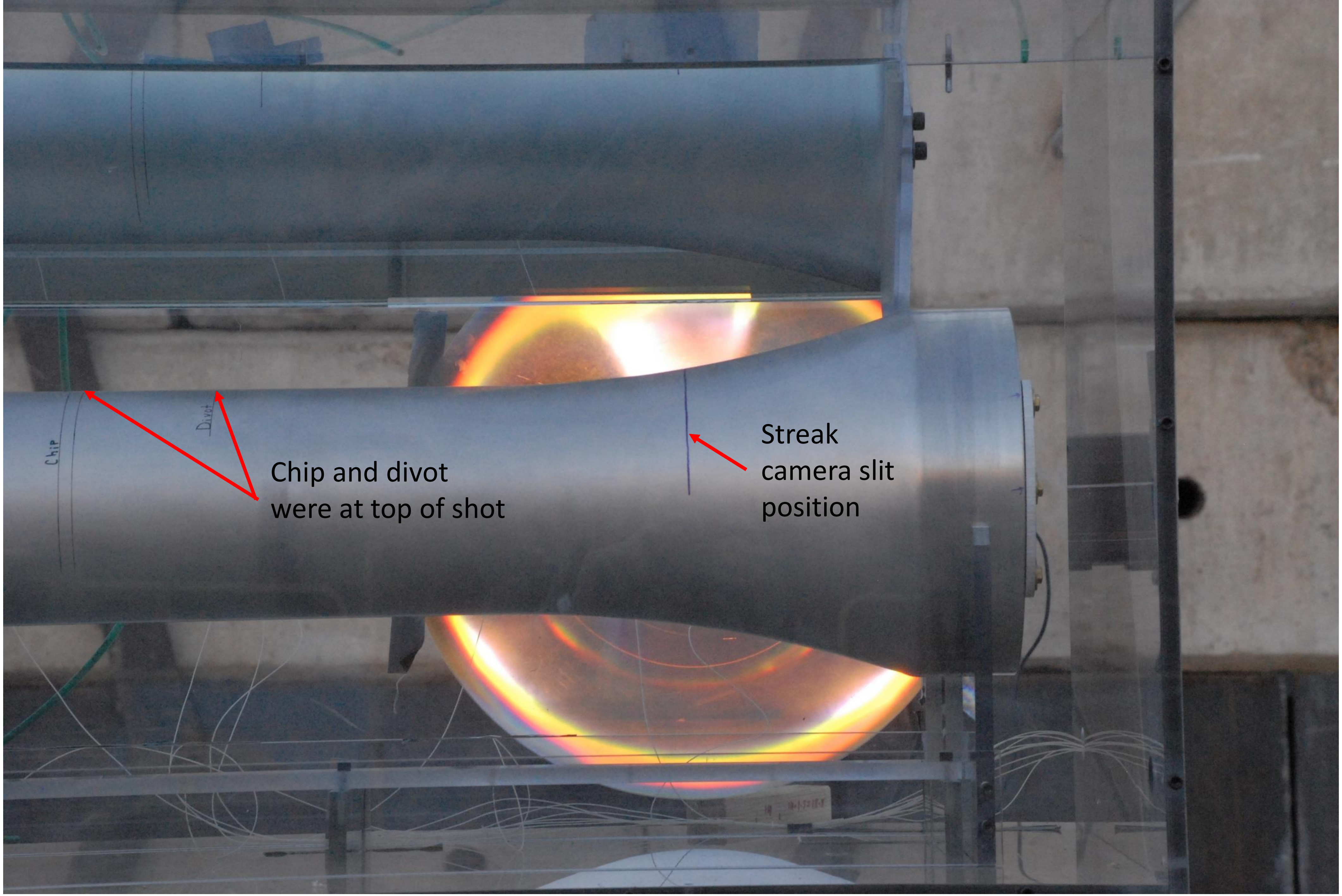

52.80μs

A Shimatsu electronic streak camera was used to record the expansion rate in the swoop region

- A streak camera photo was taken in case PDV probes in the (slanted) swoop section did not get enough signal back to give velocity data.
- A Fresnel lens was used to backlight the armature, and a very good record was obtained.
- Since very high fidelity PDV data were obtained, most of our analysis depended on them



The analyzed streak record is plotted with PDV data on view graph 70


Chip
Divot
Chip and divot
were at top of shot
Streak
camera slit
position

The following photos show the locations of PDV probes and positions are:

Ch1 is normal to the 1st detonator at the straight end
Ch3 is normal to the middle detonator at the straight end
Ch2/4 are normal to the middle detonator spaced 1/2 det spacing apart from Ch 3
Ch5 is normal to the end detonator at the straight end nearest the swoop

Ch6 is parallel to the 1st detonator at the straight end
Ch7 is parallel to the middle detonator at the straight end
Ch8 is parallel to the end detonator at the straight end nearest the swoop

Two channels (9 and 10) are upshifted to allow more accurate low velocity profiles and to allow higher velocities to be recorded (up to 20 mm/μs.)

Ch9 is on the swoop section 20.152" from the 1st detonator at the straight end
Ch10 is on the swoop section 24.152" from the 1st detonator at the straight end

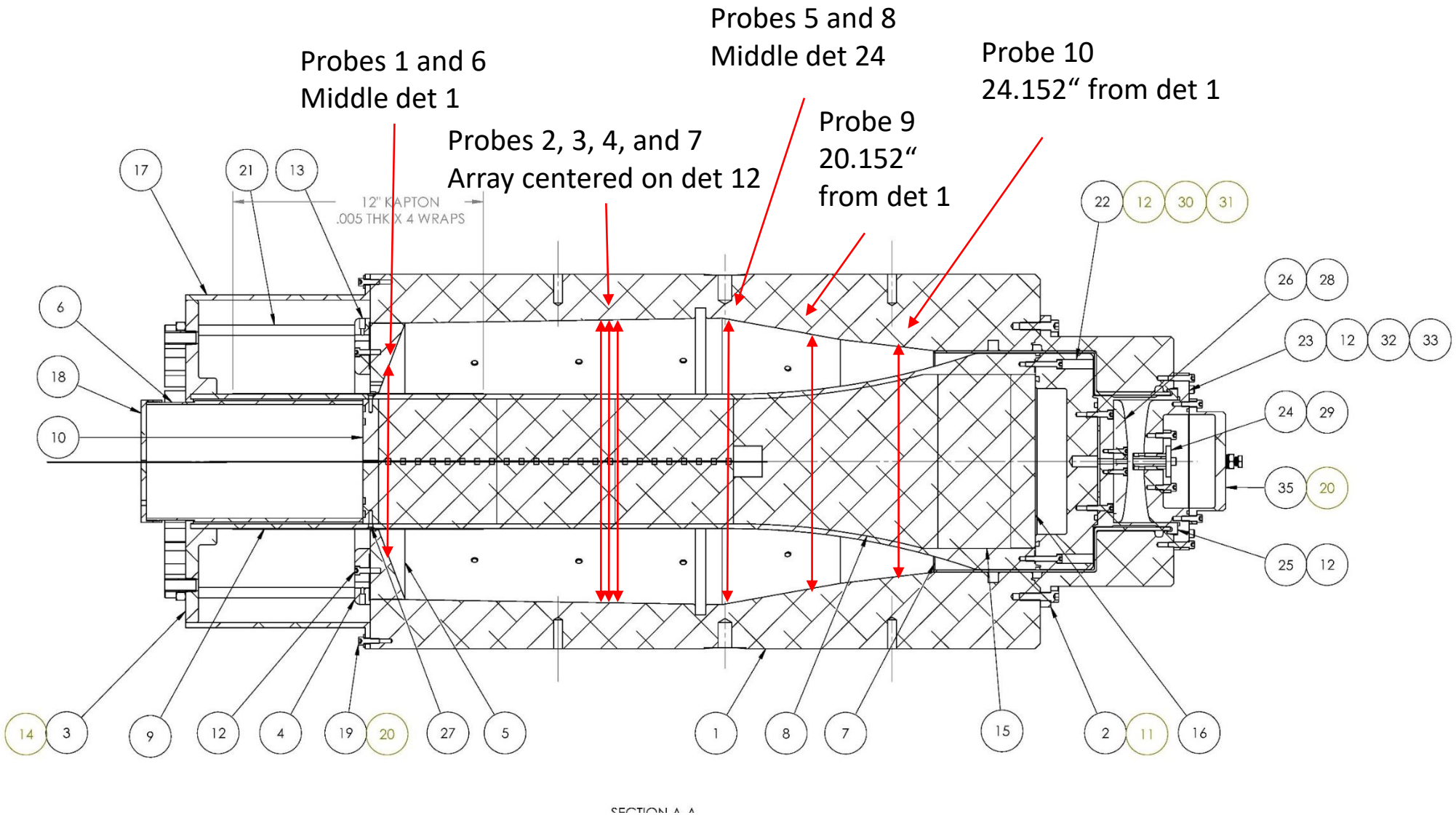
The radius of the glide plane at point of impact is 11.5 cm for Channels 1 and 6
The distance the armature will travel to the glide plane impact point is 11.5 cm- 8.22 cm = 3.28 cm for Channels 1 and 6

The radius of the stator is 17.1 cm for channels 2, 3, 4, and 7 (the change in radius of the stator is only 0.028 cm for an 18 mm det space) and the armature will travel 17.1 cm – 8.22 cm = 8.88 cm to stator impact

The radius of the stator is 17.42 cm for channels 5 and 8 and the armature will travel 17.42 cm – 8.22 cm = 9.2 cm to stator impact

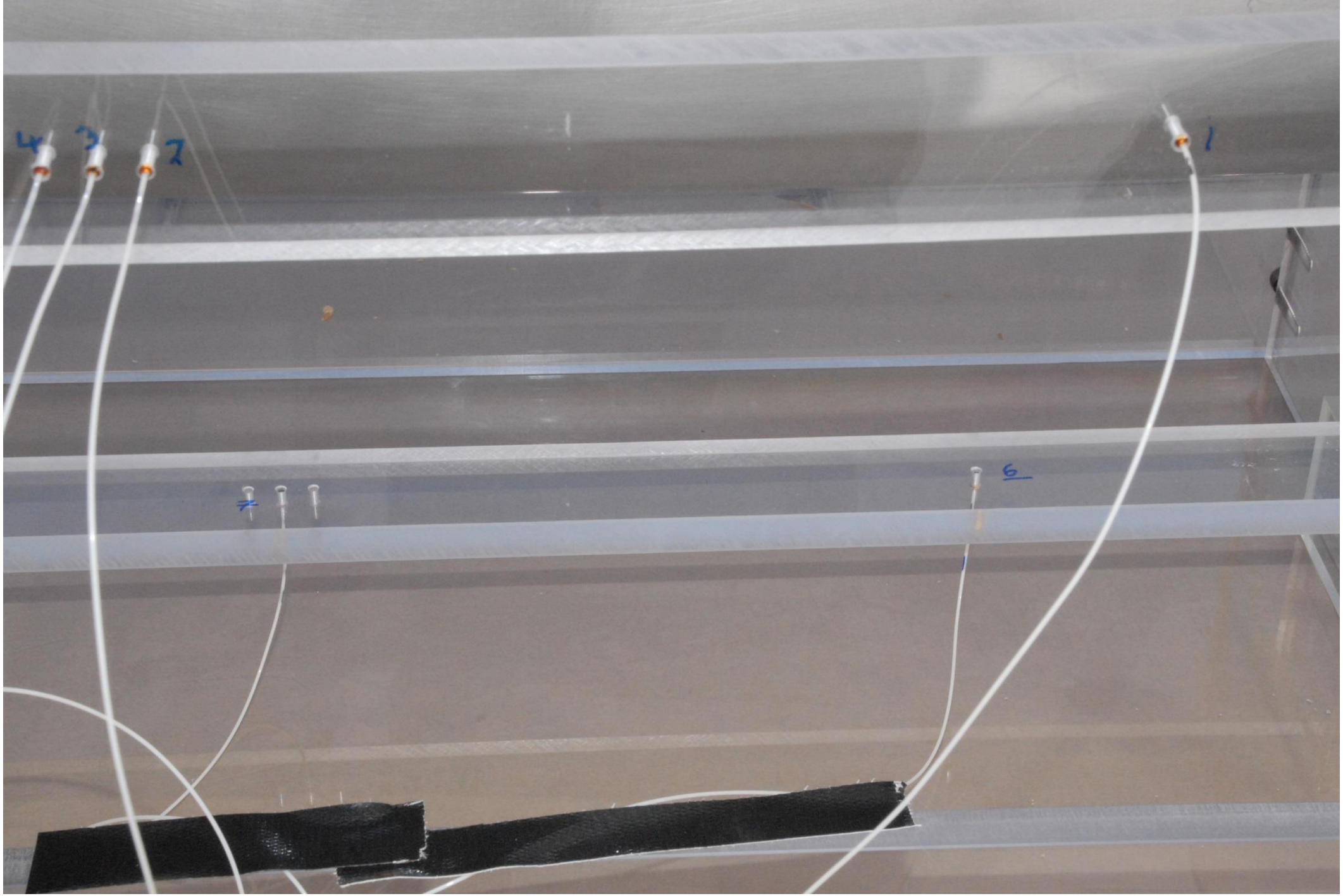
The radius of the stator is 15.5 cm for channel 9, and the distance the armature travels to impact is 15.5 cm – 8.733 cm = 6.67 cm
The radius of the stator is 14.1 cm for channel 10, and the distance the armature travels to impact is 14.1 cm – 10.4 cm = 3.7 cm

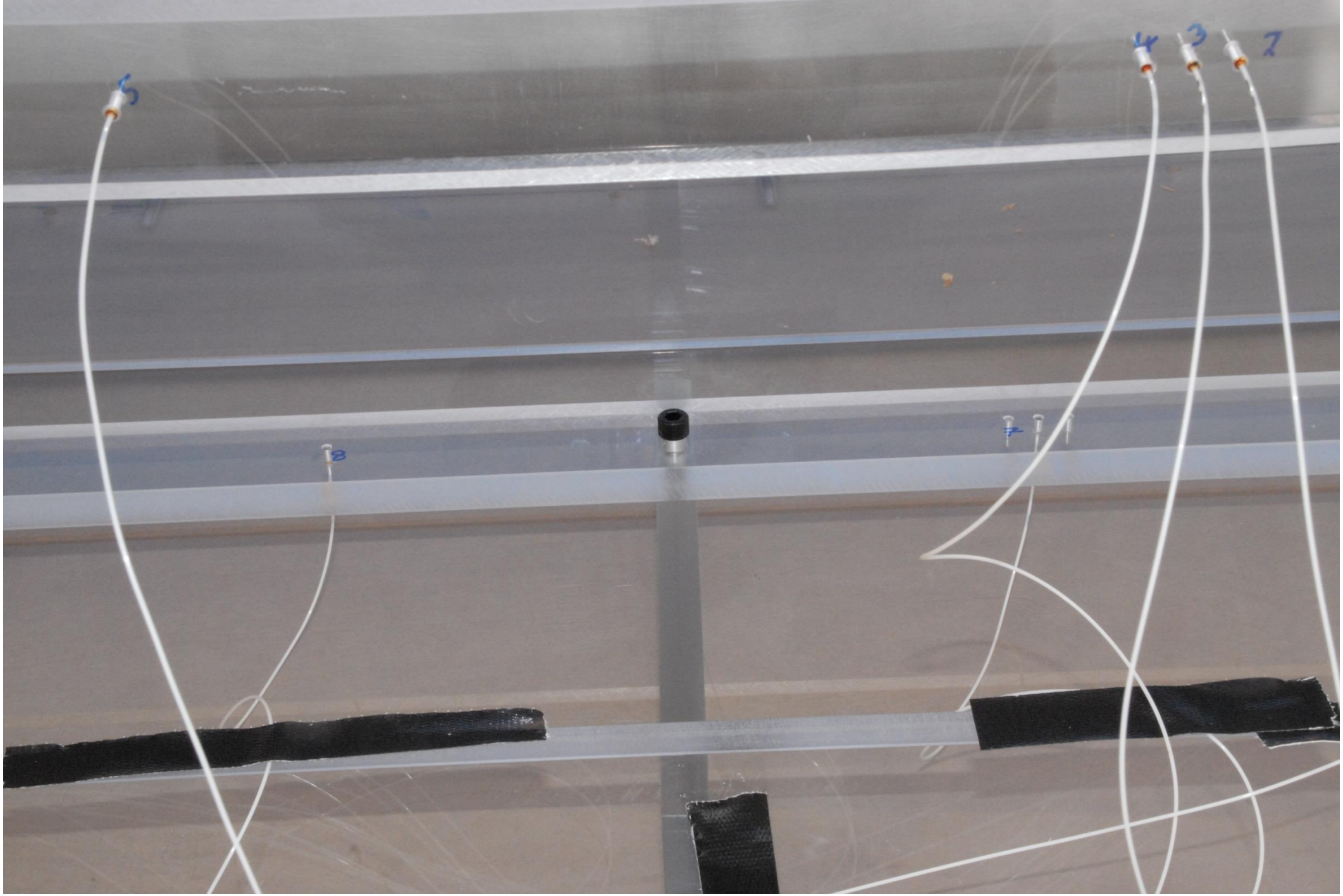
Z location of the PDV probes on LA-43-S-CT relative to the LA-43-S assembly




10
9
5
4, 3, 2
1
8
7
6
QUALITY ALUMINUM FOIL
TAPE 357

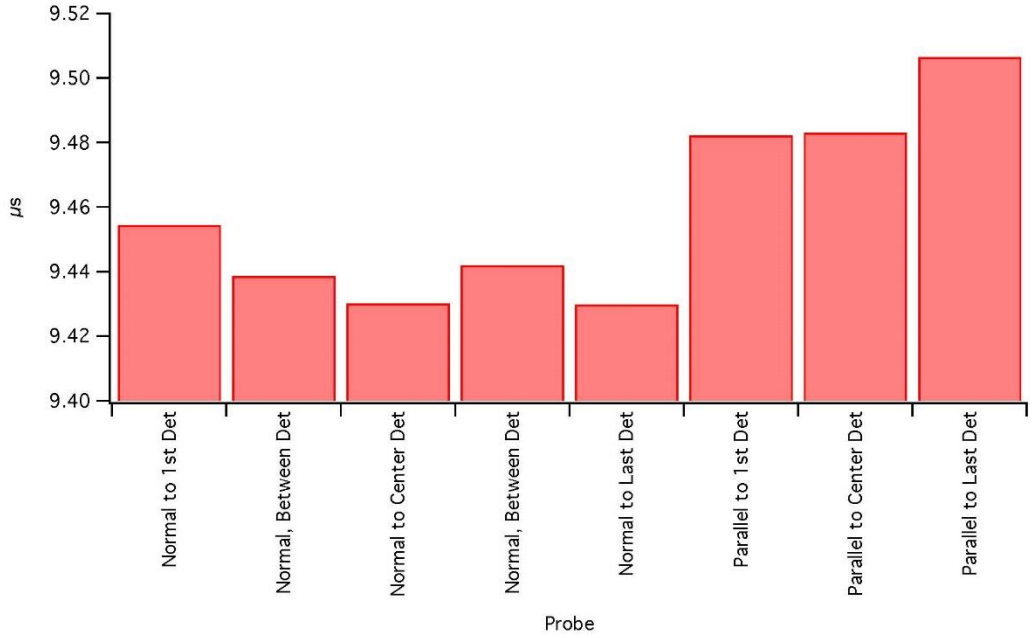

Chip location
10
9
5
4
3
7


4
3
2
1
7
6


5
8
7
4
3
2

High precision jump off times were recorded for all PDV channels

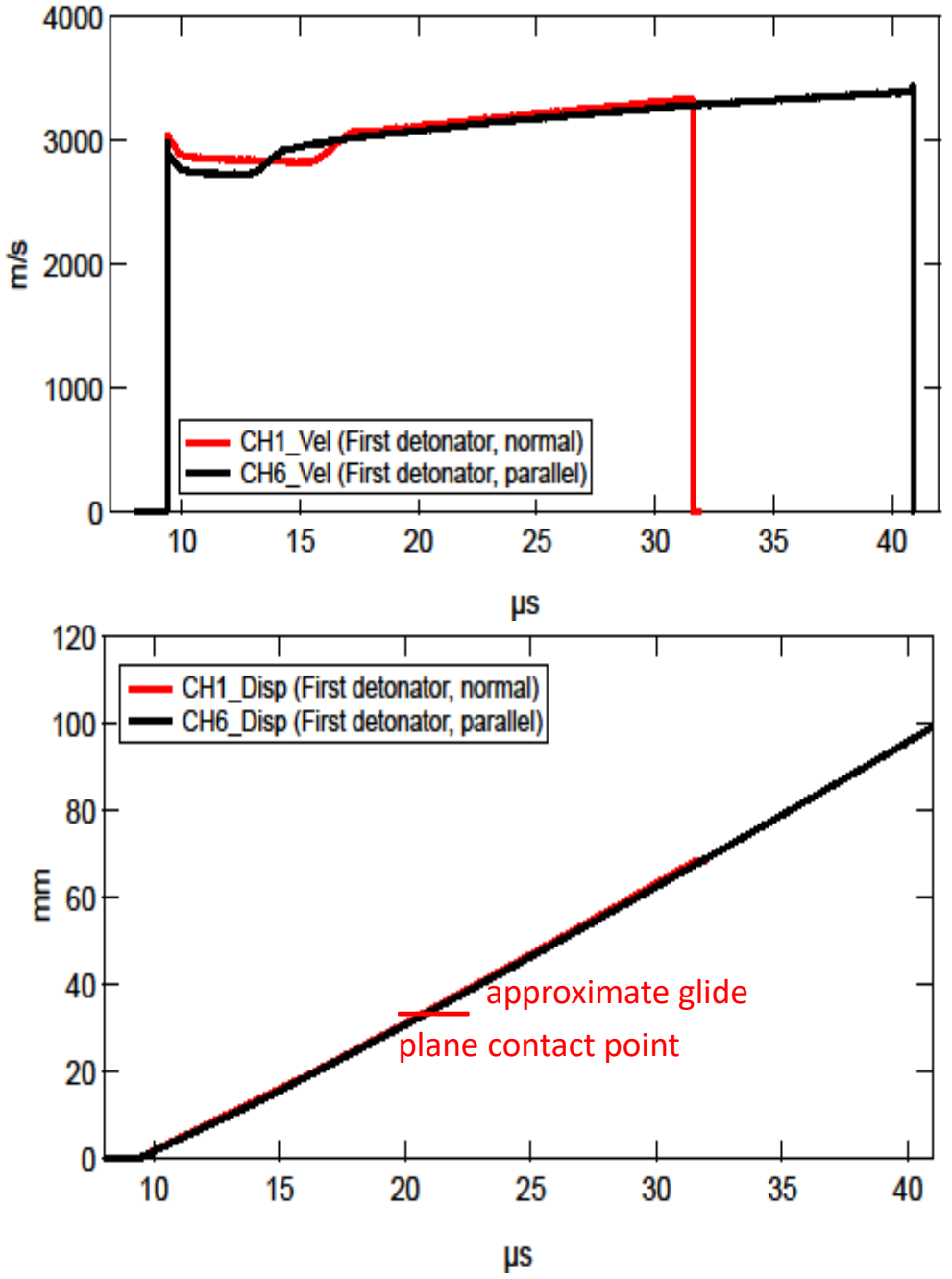
- The spread in the “normal” jump off times is 24 ns
- The difference between normal and parallel jump off time for 1st det was 28 ns
- The difference between normal and parallel jump off time for center det was 53 ns
- The difference between normal and parallel jump off time for last det was 77 ns



Point	Jump_Times	Probe_Pos
0	9.45438e-06	Normal to 1st Det
1	9.43856e-06	Normal, Between Det
2	9.43018e-06	Normal to Center Det
3	9.4419e-06	Normal, Between Det
4	9.4298e-06	Normal to Last Det
5	9.48214e-06	Parallel to 1st Det
6	9.483e-06	Parallel to Center Det
7	9.5064e-06	Parallel to Last Det
8	1.5399e-05	Swoop Section Proximal
9	2.6579e-05	Swoop Section Closer

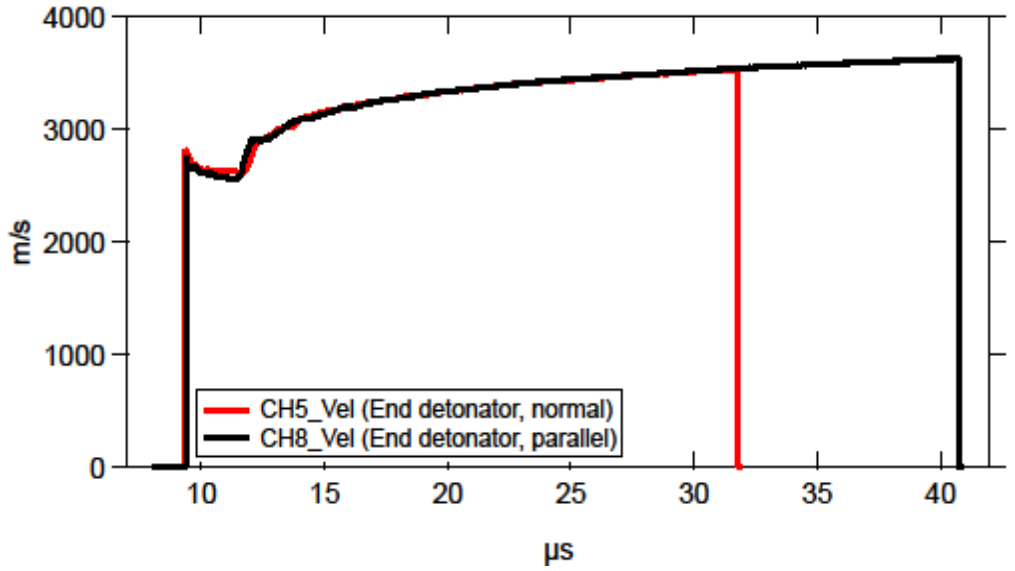
Channels 1 and 6

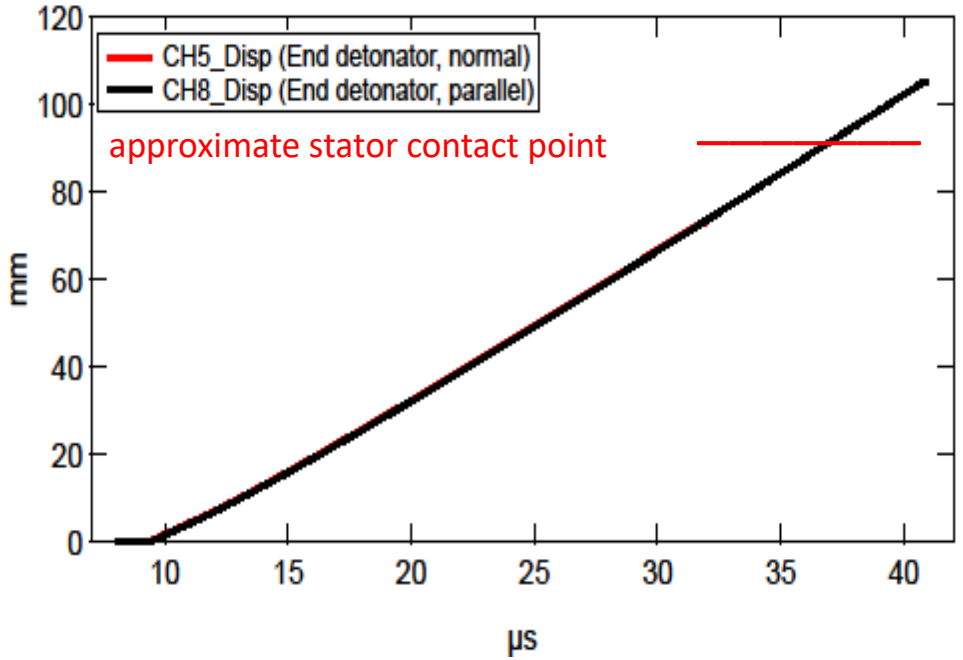
- Note that the armature in the position normal to the pellet recollects later that the one parallel to the pellet
- The armature in this position hits the glide plane after traveling 32.8 mm



PDV channels 5 and 8

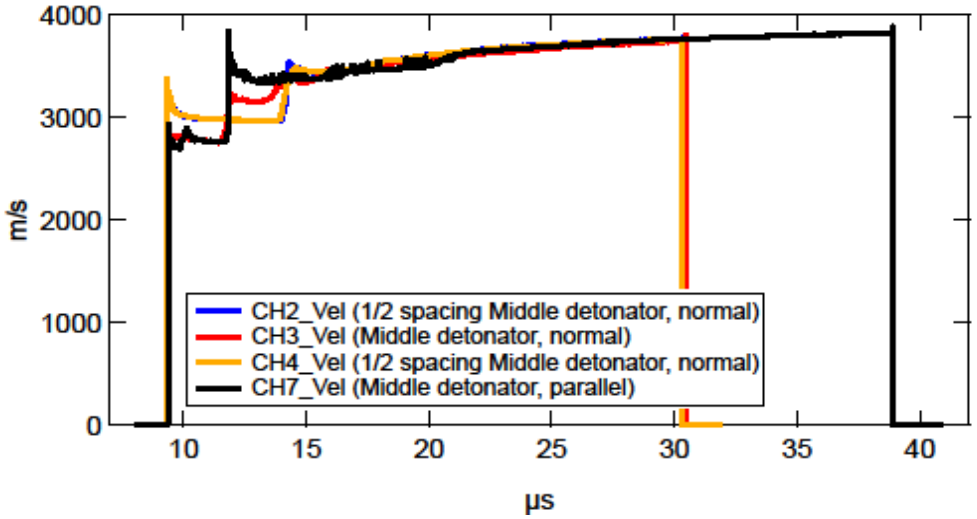
- Channel 5 ends when it hits the PDV mounting fixture seen in the photographs above which is closer than the actual position of the stator in a 43-S generator
- The armature in this position hits the stator after traveling 92 mm

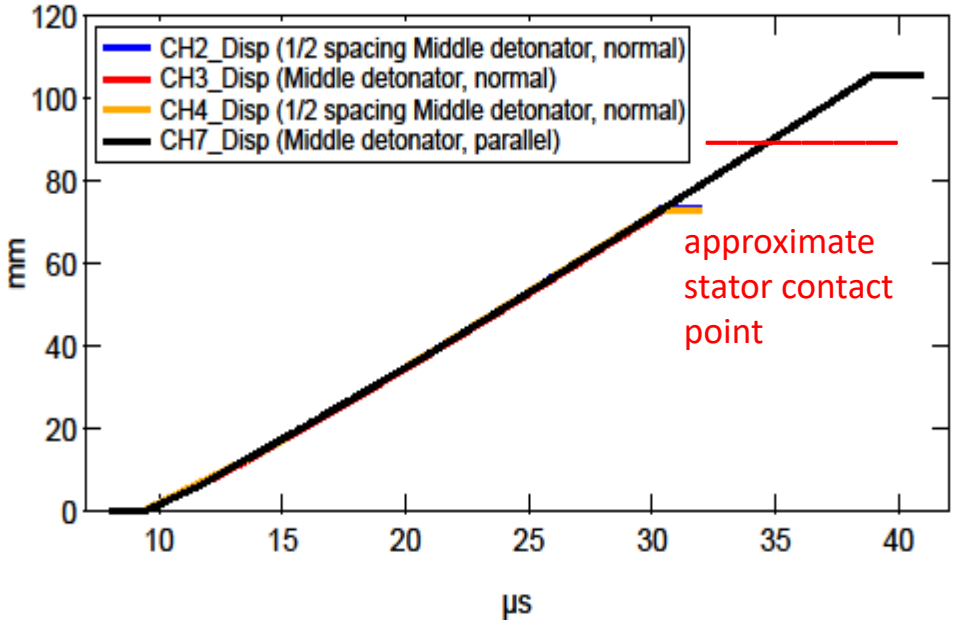




PDV channels 2, 3, 4, 7

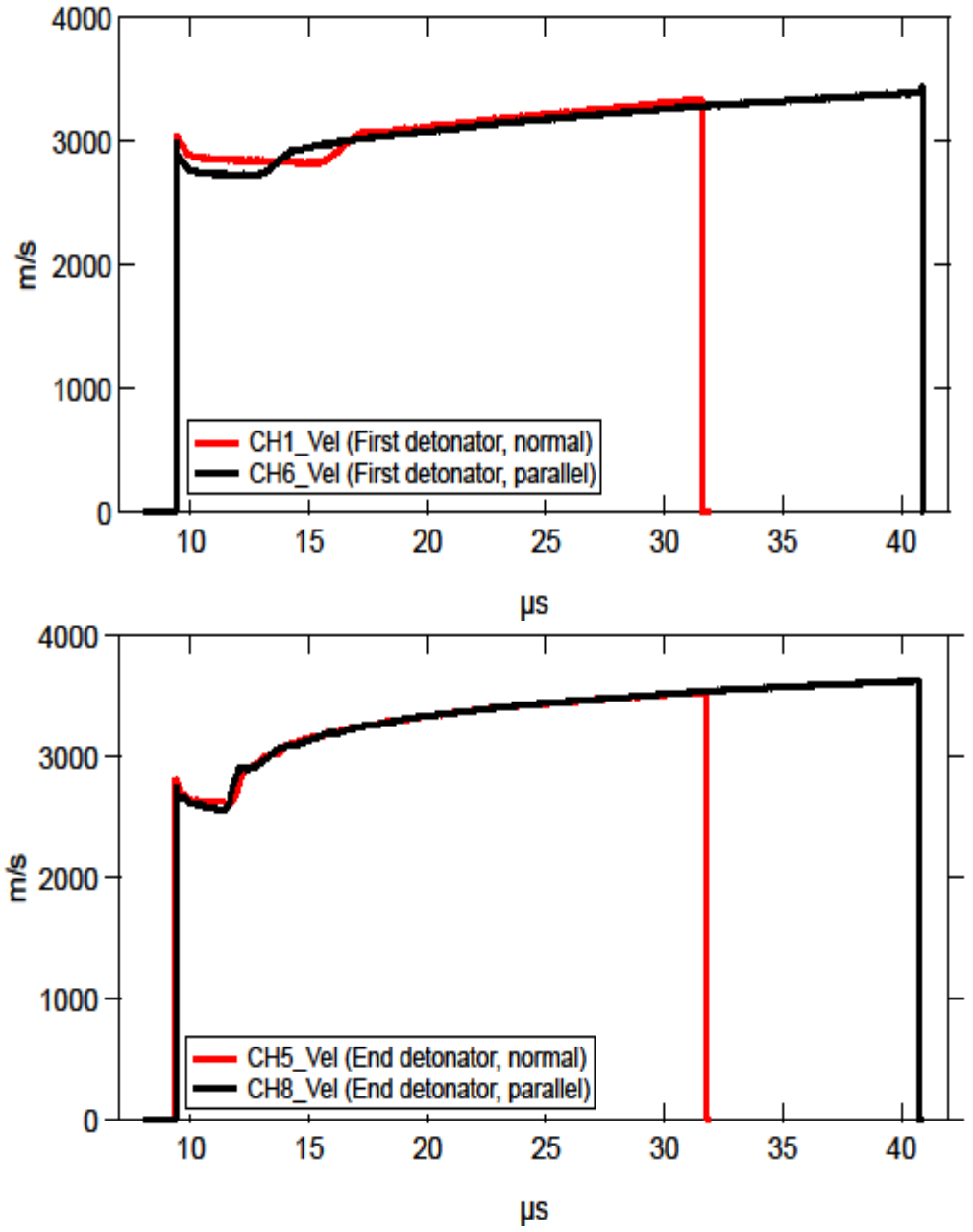
- Channels 7 and 3 recollect at the same times as do channels 2 and 4.
  - Channel 7 looks at the middle detonator from the parallel angle
  - Channel 3 looks at the middle detonator from the normal angle
  - Channels 2 and 4 look at the inter pellet position from the normal angle
- The armature in this position hits the stator after traveling 92 mm
- The PDV holder was closer for channels 2,3, and 4 than the expected stator position of a 43-S generator.





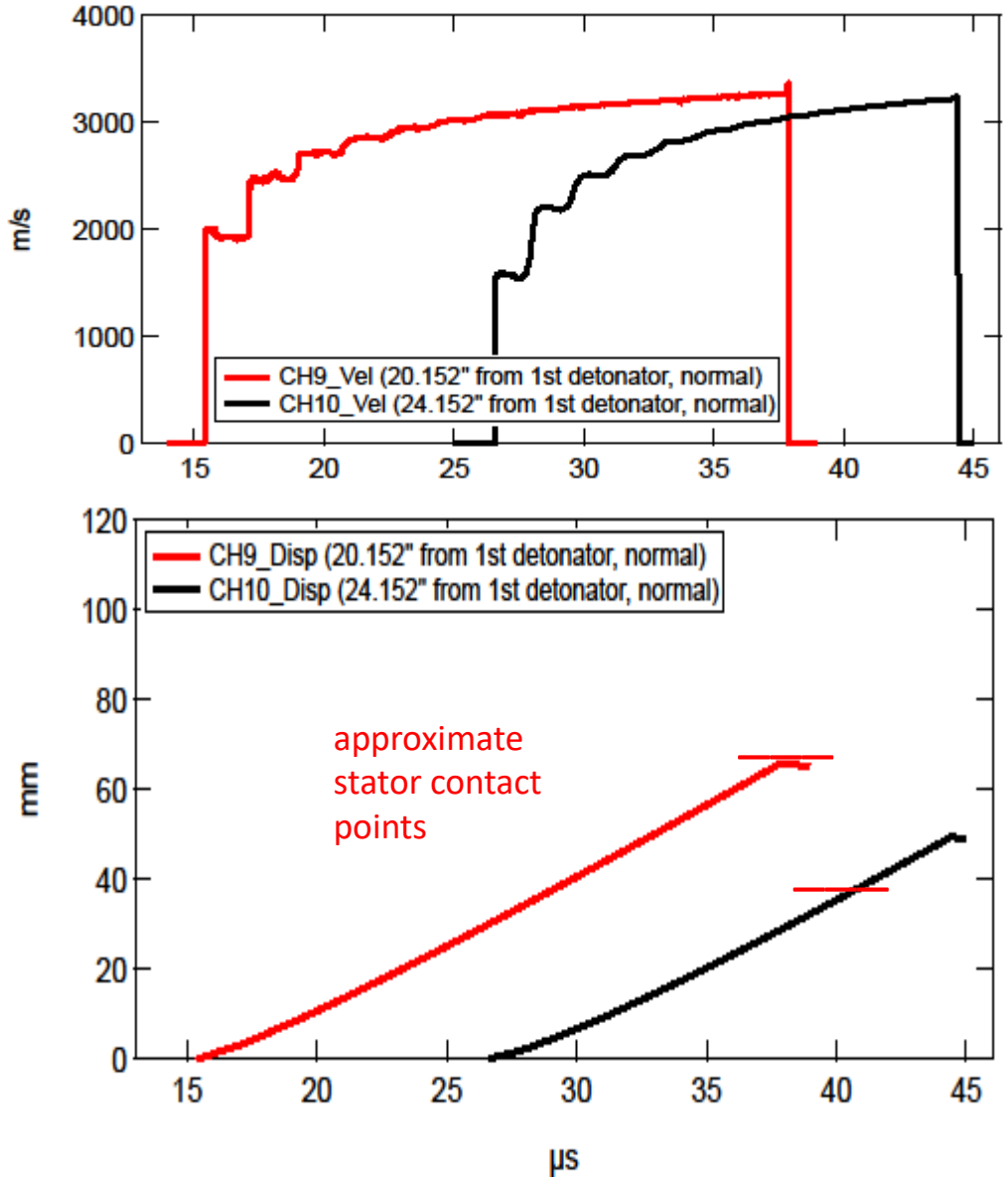
Comparison between channels 1 and 6 versus 5 and 8

- Channels 1 and 6 are only 9 mm from an unsupported HE surface
  - The recollection occurs much more slowly than it does on probes 5 and 8 which do not have a rarefaction due to the unsupported surface
  - The terminal velocity at ~41 µs is 3293 m/s
- Channels 5 and 8 are not near a rarefaction
  - These two do not recollect exactly the same, but much closer than seen on channels 1 and 6
  - These two channels recollect in roughly ½ the time that channels 1 and 6 do.
  - The terminal velocity at ~41 µs is 3605 m/µs



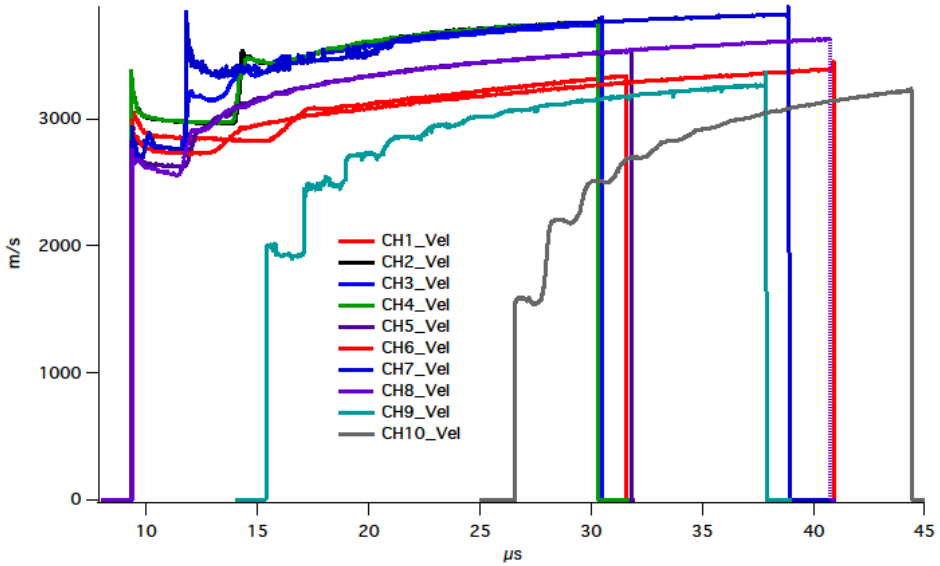
Swoop PDV probes

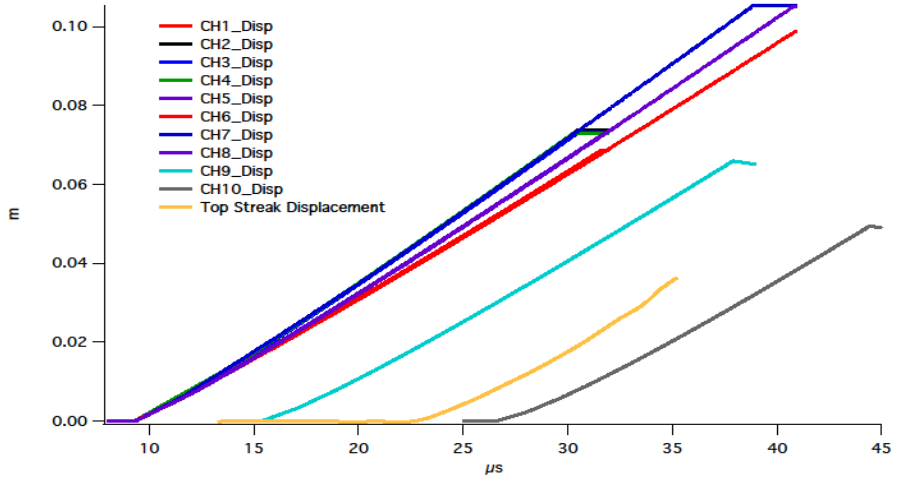
- Top graph is for the two PDV probes located in the swoop region.
- The distance traveled until impact with the stator on a full up Ranchero 43-s test will be:
  - Probe 9 – 66.7 mm
  - Prove 10 – 37 mm
- Probes 9 and 10 look at the armature where the detonation is not perpendicular to the armature motion
  - Probe 9 reaches 3.2 m/s
  - Probe 10 reaches 3.1 m/s at approximate contact time and hits the PDV holder at 3.2 m/s



PDV records for all channels

- Good data are recorded for all channels
- The streak record is shown in gold on the bottom plot.





1/5/16 - Philip and Chris

Below is a comparison plot of the FLAG to PDV data. The agreement is not terrible, but there are some issues.

Flag nails the final det profile (5). It under predicts (1), but that one is tricky owing to the end effects. It does well on (2-4) except for under predicting the final velocity. It does well on the initial ring up.

The ring up for (9) is quite far off.

The jump off time for 10 is quite far out. The obvious thing to do there is check we all have correct coordinates for that probe.

Philip

On Jan 4, 2016, at 14:46, Rousculp, Chris <rousculp@lanl.gov> wrote:

Hi all,

Here's the movie of the Flag simulation. Red lines on the right indicate the PDV channels looking from right to left at the armature.

I don't presently have a way of simulating the parallel vs perpendicular orientation of PDV channels that was fielded.

Also attached is a tar file with the extracted PDV channels that was used to make the previous plot.

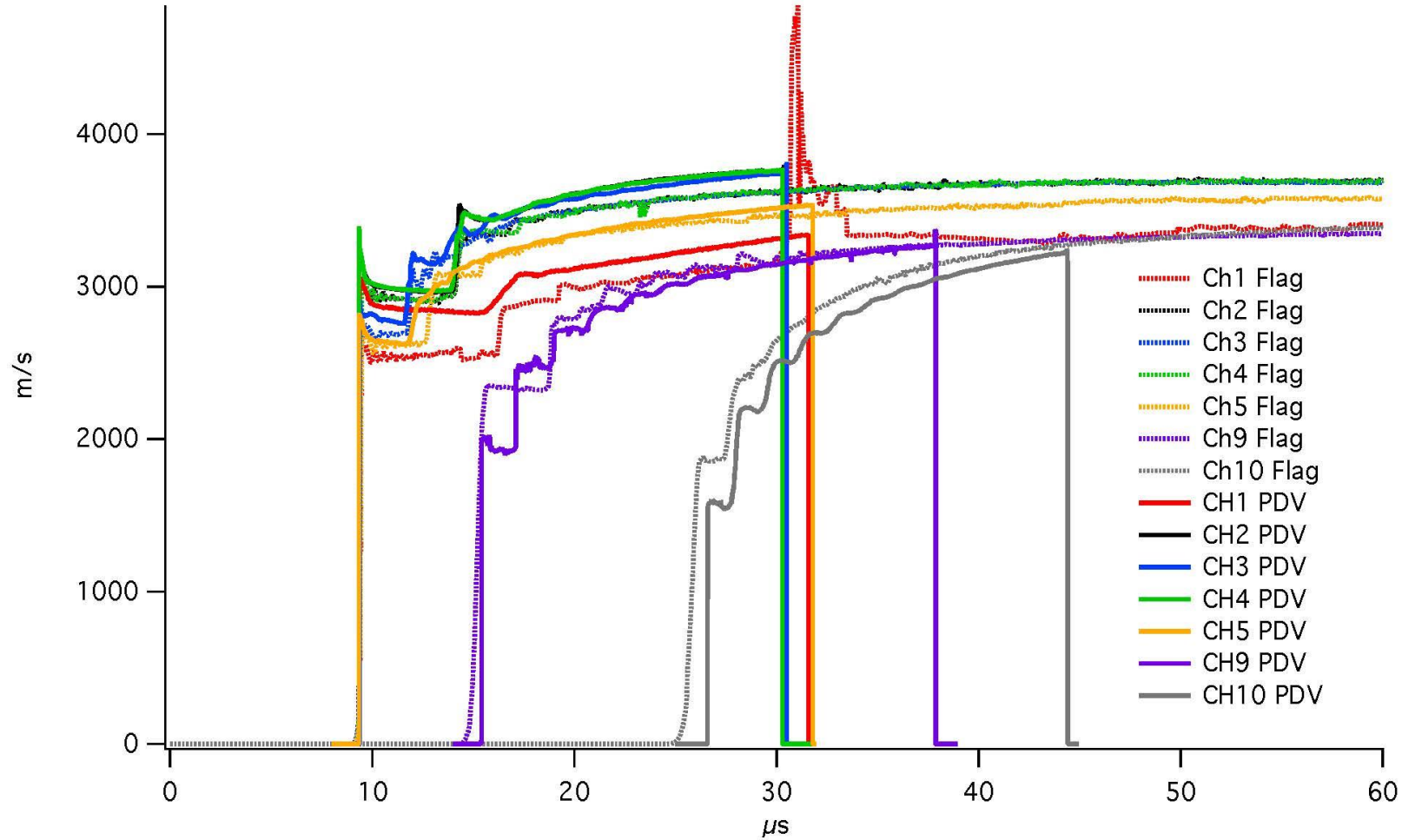
Feel free to compare to the experimental PDV data.

Chris

<withDamage.mov>

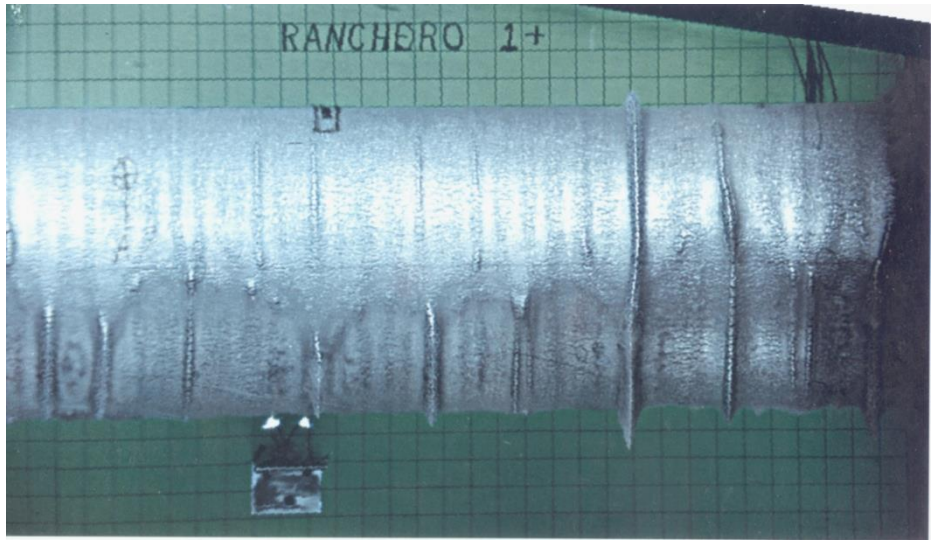
<Ranchero43SW-CT-PDV.tar>

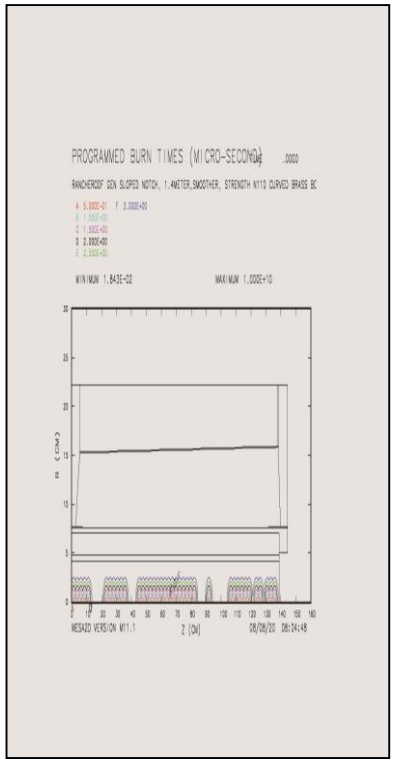
PDV records compare well with Flag calculations

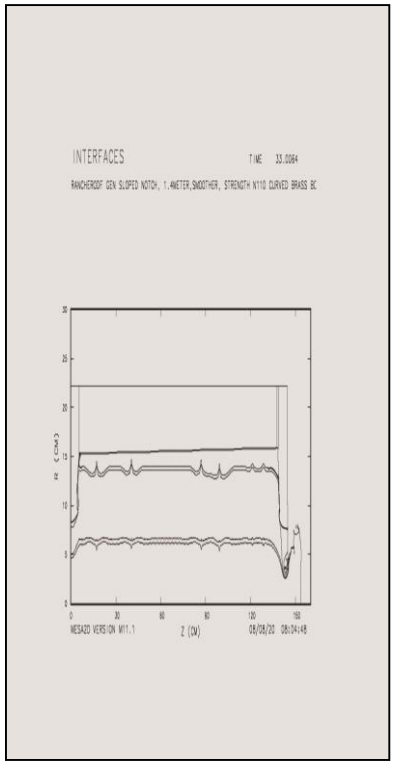


3 mm long/6 mm diam 1.65 initiation pellets are adequate to promptly detonate PBX 9501

In 1999, to provide a lower firing threshold for the new 56 point 1.37 m long system, very high surface PETN was used at 1.55 g/cc in 12 mm diameter hemispherical boosters in place of the 1.65 g/cc PETN used in Ranchero work up to that time. Very poor performance was observe, as shown in this late 90s armature development test. In spite of the general belief that such boosters would be adequate, and computer simulations that gave further reassurance, it was eventually shown that those boosters will not promptly detonate the PBXN-110 at every point. An important result from LA-43-S-CT was to demonstrate that the 3 mm long, 6 mm diameter 1.65 g/cc boosters used in the assembly were adequate for prompt initiation of the PBX 9501.s







MESA hydrodynamic calculations show the effect of not detonating all the points of the line detonator array, and the calculations reflect the experimental result shown here.

Conclusions

- Good slapper performance
- 6 mm diameter, 3 mm thick standard grade PETN pellets at 1.65 g/cc are adequate
- The maximum delay at the waist was 77 ns
- Divot didn’t blow out
- Chip may have blown out at late time
- One small blowout at bell joint near full expansion
- 10 mil Air Gap along cylindrical HE did not hurt.
- Velocities are adequately predicted by codes
- Performance is adequate for a full scale Ranchero 43-S pulsed power shot.